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PSYCHOLOGICAL OPTICS

BOOK III

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P S Y C H O L O G I C A L O P T I C S

by

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MOTOR THEORY I

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Upon some reflection it seems obvious that due and fitting emphasis should be placed upon the essential and fundamental facts of body movement, and of the role of the effector processes.

Why, in the history of the life sciences, have we delayed so long in including the terminal and consummatory acts and their consequences as agents of organization and reorganization in the behavior cycle? Why was it necessary to wait until 1943 for a neuro-physiologist to write that "the central nervous system is organized, not in terms of anatomical segments, but in movement patterns" (Fulton, J. F., The Physiology of the Central Nervous System. p. 51)? Why, since the whole evolution of the synergic functions of body systems is centered about the vital collection, storage and transformation of energy, have the effector mechanisms of the body received, until comparatively recent times, relatively meagre consideration? Why has the emphasis upon the functions of sense organs, and of the brain cortex received such disproportionate emphasis? Why, particularly, since one has not far to look to find the substantiating evidence for Professor Fulton's important generalization, quoted above? One can go a step farther: The central nervous system not only is organized in terms of movement patterns, but movement patterns are primary agents of organization of the sets of systems within systems which comprise the unified behaving organism able to sustain itself in its station or habitat in life.

It shall be our purpose in this, and some papers to follow, to summarize the principal postulates of motor theory and cite the foundational and substantiating theory and research as it stands today. Our primary interest, of course, is in the problems of how we see. We shall not be unmindful of them. It shall be part of our duty to point out the fact that Nuel, the Belgian ophthalmologist, many years ago showed that visual perception depends not upon mere reception, but upon action-patterns or sensori-motor coordinations. If tonus or tonic and postural reflex mechanisms are unbalanced, then tension gradients produce a 'relative localization' and a shift to some other object in the visual field as its phenomenal standard of reference. Egocentric localization is localization of an object with reference to a body system, which has a motor basis (Purdy).

Goldstein's brain injury patients with disordered muscle tonus and motor disturbances also showed anomalies of space perception. "In each case the phenomenal displacement of visual objects was in the same direction as the motor deviation tendency."

It is also interesting to note that Goldstein and Riese produced similar results in normal subjects simply by cooling the skin of the neck on one side to produce a unilateral atony. Again visual displacements paralleled the motor deviation tendency.

Anatomists have pointed out for many years the persisting relation between the second and the eighth pairs of cranial nerves, i.e. between the visual and vestibular mechanisms in the orientation of the body in space.

The destructive effects of hypertension, "pressing" or anxiety states on all skilled movements is well known. It has been shown that the true skilled movement is marked by the transformation through learning or training of a tension movement into a ballistic type of movement. The tension movement is one in which the muscles contracting throughout the course of the sweep of the arm, for example, are continuously opposed by the

braking action of antagonistic muscles. The direction and rate of the motion is thus a sort of algebraic summation of the two sets of opposing forces.

In the skillful or ballistic movement, on the contrary, it has been shown (Stetson, McDill, Bouman, et al.) that the limb is thrown forward by a quick, relatively unopposed flexor contraction, lasting approximately 1/20 second: that the moving limb swings freely in its stroke and eventually comes to rest in a natural 'follow through' without the abrupt braking action of the opposing extensors. What happens in hypertension, emotional or anxiety excitement? There is a regression from the level of smooth, fluent, efficient ballistic skill to the less accurate and less effective earlier-stage tension movement. The tension state tends toward disjunction and disunity.

Conversely when tonus is lowered by depressor drugs, or in "consequence of fatigue, beyond a certain limit" there is a similar reduction in movement organization. When the muscles reach a final sufficient low tonic level the end result is - sleep and unconsciousness.

Edmund Jacobson showed convincingly by his many experiments that by long training in progressive relaxation he could establish voluntary control of the process of reducing tonus. His subjects consequently could at will abolish visual or auditory imagery: could elevate thresholds or could attain a sound natural sleep in a matter of minutes.

The working of the effectors, particularly the muscular system, is the essential framework upon which must emerge all sense-perceptual processes. If for any reason this component is lost by too much or too little tonicity, the degree of loss is paralleled by a similar loss or even complete ablation of what we may call the mental life.

Dodge has shown that everyday behavior is "not a mosaic of separate or discrete responses" but is a "dynamic continuam" - "a sort of spiral process with a comparatively simple front of overt reaction at any given moment and a highly complex background. Adequate experimental analysis would probably show that each overt reaction is really a complex of approximating beginning reactions and elaborated adjustments. The beginning reactions are evoked by current stimuli superimposed on the remains of consummated responses to the past stimuli by which they are inhibited, reinforced, or qualitatively modified. Each protopractic phase as it emerges is modified by the effects of more or less elaborated sense data from the same situation stimulus, which in turn may modify the next protopractic phase of the response."

Behavior thus is not a series of occasional acts or movements set going by antecedent sense-perceptual impressions. The continuity and unity of the stream of behavior must be set down as a basic postulate, and the purely sensory impressions themselves regarded as likely sub-orders or movements in the stream belonging to Dodge s classification of "approximating beginning reactions."

Strangely enough Dodge formulated his thinking (and how weighty it is.) after observing that in pursuit movements the eye often reached the end of the swing and began the return sweep coincidentally with the moving target, <u>or even a little ahead of it.</u> If the target stopped, eye-movement often continued for an appreciable time. Response, he said, was not being made to successive positions of the object as a chain of discrete stimuli. Rather <u>some kind of integration in a unitary response pattern must be operative.</u>

I have tried to show from experimental observation in visual form perception, the unification of the perceptual pattern begins in the prodromal foreperiod, well in advance of the retinal excitation. If we go one step farther, along with Dodge, with F. C. Bartlett s Schemata, with Stetson s analysis of the simple voluntary movement, we see the clear sameness of attributive properties, yes the essential oneness of cycle of (1) motor adaptive or adjustory prodrome (2) excitation of the sense organ (3) central supplementation and distribution (4) effector movement (5) backstroke (6) readjustory set, with the series beginning again with (1) now, of course, in new space and time relations.

By such a unitary motor theory we free ourselves from the shortcomings of both an out and out sensori-motor dualism in

which there is no telling where one begins and the other ends. We may also avoid the difficulties inherent in Wertheimer's isomorphism.

Gestalt theory has rendered a great service to Psychology and to psychological optics. The experiments and the theoretical developments in the field of perception alone have been of inestimable value. The arguments, and the evidence, against the elementarism of the sensation-association doctrines have been potent and unanswered. No fair minded scholar can familiarize himself with this literature and fail to be impressed by its soundness and its worth. The test is that when we set up experiments according to configurational principles, they "work."

There is however, a conspicuous weakness. With all the brilliant theory and experiment on visual perception, on the discrimination functions of the sense organs, on figure formation and figural after-effects, there is an almost complete disregard of the effector processes and the strong influences exerted by the processes. Purdy and others have pointed out that the motor processes can and do transform the sensory. While it is true that both Köhler and Koffka have emphasized the strong reconstructive influence on subsequent acts of the consequences of any earlier trial or exercise of a function in learning to meet a problematical situation, yet the treatment is scanty and leaves much to be desired. Of course in strict fairness it should be pointed out that this field of investigation - motor theory - is a comparatively new and unexplored region; that it is quite unfair to complain of the failure to be farther along the way to truth when even the briefest backward look impresses one with the tremendous accomplishments already achieved.

Notwithstanding we must realize that the active attack upon problems set by motor theory must go forward now.

There are a number of basic facts we must keep in mind in setting up the basic framework of motor theory. Some of these are at variance with rather widely held popular views. One of these may be taken as illustrative of the general case. From a paper I wrote in 1938 I quote "The motor innervation of two adjacent but differently supplied adductor muscles is surgically reversed. Upon recovery nerve A, which now excites muscle B to shorten, discharges. If the shortening by B is one factor in a pattern reaction incompatible originally with any innervation from source A, B maintains its functional integrity independent of any quantitative or qualitative characteristic of the motor discharge through A."

This principle is now a common surgical practice in the treatment of certain diseases. Anrep and Beck were the first to give relief from the overwhelming pain of Angina pectoris by giving to the heart muscle a new source of motor innervation. In certain types of blood disorders dramatic results are commonly secured by giving to the spleen an entirely new source of innervation. I am assured by a colleague, a research professor of surgery, that such procedure is widely and successfully used every day.

One inescapable conclusion follows: The pattern of effector action is not set or predetermined by the brain. If it were, a portion of the branchial nerve which now goes to the heart muscle would accelerate the heart every time the patient willed to contract the muscles of his forearm. But, it does not.

Since the central effector discharge is not the decisive determinant of the response pattern, it follows that the stimulus-impression upon the sense organ is similarly neither the determinant of the central conduction gradients nor of the consummatory response series. The effectors themselves must serve therefore as something more than just being effectors. This 'something more' will be the subject of consideration in later papers of this series.

Finally, let us remember that in the embryogeny the skeletal muscles are often well developed in advance of the anastomosis of the terminal arborizations of the motor nerves.

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

MOTOR THEORY: II

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We have noted in the papers of volumes 5 and 6 of this series some of the facts and some of the main theoretical trends regarding fields and the formation of figured structures within fields. These things have important practical consequences. Where anomalies of visual space produce discomfort and inefficiency they are practically uniformly indicated. Unity gives way to disjunction. Competing tensions lean to blurring, doubling, loss of meaning, particularly because there can only be, as a resultant of central cortical disorganization, incompatible effector response systems.

There can be no question as to the scientific importance of these principles. It is entirely possible that some of the greatest developments in helping us to understand and control seeing will find their origin in studies of problems of this type. In the province of visual space and form perception we have already seen numerous instances; the work, for example, of Gibson, Köhler and Wallach, Koffka, Bartlett, Graham, to mention only a few.

There is no doubt that the introduction of such concepts as configurationism or Gestalt principles, holism, the organismal theory, etc., has had a wide spread influence, and is greatly influencing research and theory today.

Opposing types of elementaristic viewpoints are not dead and not everyone is willing to accept and put to work the molar as opposed to the molecular type of thinking. Most of optometric education is probably still of the latter type - in some quarters it is exclusively so.

The advocates of such a viewpoint often raise a question which they aim at what they regard as a vulnerable point. The question is this: Is there any real difference between the field organized according to associationistic principles from that organized according to configurational principles? If a figure on a ground is an aggregation of objects or processes segregated from its surrounds, is there any real difference between this and a central group of processes conjoined in association and surrounded by a contextual fringe?

Either way, they hold, you are confronted by the same sets of objections, namely the difficulty of finding the determinants of the plan, direction and range of the field structure and of dealing satisfactorily with the problem of meaning.

Let us look for a moment at association theory and how it secures figure structures. Later in this paper it will be shown why it is important for a proper understanding of motor theory to clarify the solution to this problem early.

Association theory is old. It is often credited to Aristotle. There are numerous variants of the theory, but a fair sample runs as follows: Mental life is a construct of elementary processes - sensations, images, simple feelings. How do these bits of experience become combined to produce forms, or percepts of objects? By the operation of the laws of association. These are similarity, contrast, simultaneity and succession.

The form of combination, they hold, is that of a center and a surrounding fringe, a focus and a margin. A group of elements, sensations and images are bonded together by association to form the nucleus. The nucleus or center is a group of processes which aggregate to form a unit because of the operation of one or more of the four

laws. As soon as this central grouping takes place it is surrounded, also because of the working of the aforesaid laws, by a fringe of contextual similar elementary processes (other sensations and images), and these contextual processes are the carriers of meaning. Meaning is context, and context is the sum total of those processes which accrue to the central or nuclear core when it is formed, according to the primary laws of association. Thus meaning is not intrinsic to the central processes but varies with the kind of context which is the setting for these processes.

Where does the context get its meaning? From other still more remote fringes which are weaker, more remote, more diffused than the primary context. To some, the problem of meaning is thus clarified by pushing it always one step farther into obscurity, and such a pure teleological hunt for the ultimate first 'cause' does not satisfy many who are scientifically trained.

This is not the only objection. Titchener showed that the four Aristotelian "laws" are purely logical constructs; that they all reduce on analysis to a single simple principle, namely coexistence in time, or temporal contiguity. The "law" thus stated says merely that to be associated, any two processes need merely to occur side by side or end to end in time.

The same able scholar also showed that something else was radically wrong with the too-easy formulation. This was that in the laboratory the law often did not hold. Under conditions in which a conjunction of twice the impression frequency as another was examined, it was often found weaker. Also he amended the context theory in a very important way. Realizing the unsatisfactoriness of the context theory of meaning, he proposed that the associating was a very real, physical process in the brain and that not sensation, images and feelings, but meanings were associated. Meaning, he said, was kinaesthesis; that is, meaning arises as the backstroke of afferent impulses which come from proprioceptors in the muscles, the tendons, the articular surfaces by the joints. Meaning derives from the perception of the motor consequences of the stimulation-reaction series of events.

What anything is, is what it does. In philology the most important words are action words, i.e. verbs, not nouns. The earliest definitions, in childhood and in the race, of words are in terms of use or action. "A fork is to eat with" is a fair sample. The earliest known languages, vehicles of meaning or communication, were languages of gesture, posture and mimesis. Some still prefer the silent movie as an effective and more rapid way of telling a story to the modern 'sound' version. It is said that some semi-savage people can only understandingly converse at night if both parties stand close enough to the campfire. Spoken language can only be comprehended if the hearer can see the expressive movements of the speaker.

Many scholars have felt that Titchener's recasting of the association doctrine was its only real improvement; others feel that all he left remaining was the name. Clearly if, as he put it, "the common denominator of all meaning is kinaesthesis," this puts the problem squarely in the center of a motor theory. Meaning ceases to be a nebulous and mystical thing, attached to the cognitive and sense-impression portion of the behavior circuit and becomes integral with the conative or executant action phase. This is in accord with the view, held by many, that in the organic evolution, the process of head-dominance or cephalization has been a process of the evolution of distance-receptors. When behavior became more complex as an enforced necessity for existence, detector and discriminating sense-organs had to evolve or there was no survival. Imagine a squirrel who jumps ten times his body length fifty feet above the ground from one branch to another whose visual space judgments were in error too short by ten percent! Or, why do we speak of the Rocky Mountain goat as "sure footed?"

The weakness, it seems to me, of Gestalt theory lies in its attempt to solve the problems of space and thing perception by limiting operations to the sets of relations between the "out there" (objects which furnish impression patterns to the sense organs) and the "in here" (processes which take place in the brain cortex). We must go a step farther. We must deal with the all-important role of the effector processes.

We must extend the theory to include the decisive determinant agency of the backstroke. With Dodge, Köhler, and others we must insist that it is the consequences of the approximating and correcting trial acts which lead to the formation of manipulatory skills. We must insist that all learning, all transforming of perceptual fields is basically and essentially motor. Guthrie was so very right when he said that "mental life is muscular life." Aside from sheer indispensability, the basic protopathic reality of object perception stems from the amount and kinds of movements I make upon being stimulated.

Curiously von Ehrenfels, who originated in 1890 the term Gestalt, which means shape, pattern or configuration, saw the way out of this basic problem. Von Ehrenfels defined patterns or Gestalten as "those mental conditions and processes whose characteristic individualities and activities are not explicable by the mere summation of similar individualities and activities of their so-called parts." The essential quality which determines a pattern, he said, is its underlying meaning.

Köhler in his learned treatise on physical gestalten and later F. Wulf were clear in pointing out that phenomenal patterns determine action patterns. All portions of the sensory-cerebro-motor system were regarded as interdependent portions of a single coherent system in which every part influences and is influenced by every other part. Helson has pointed out that for configurationists "motor reaction-patterns are determined in their temporal order by the end or goal which may be an integral part of a configuration even though it is not present in time and space. Part activities can thus fit into meaningful ordered wholes for which the ground of connection is the concept of the configuration." Goal orientation, i.e., a prodromal set, precedes in time the actual series of sensory impression patterns and is a powerful determiner of the course of action to the attainment of the goal.

The facts in the case seem thus to be that the difference between the two points of view, holism and associationism, lies in the much broader formulation given by holistic theory; by the fact that it alone places the all important consummatory act as a primary phase of the coherent and unitary process of field and figure relations; by the fact that it accords with the general theorem of Lloyd Morgan's emergent evolution, and finally that it presents a theory of meaning which is freed from the manifest objections inherent in the context doctrine. Even if one were to accept the principle that meaning derives from context and context is merely the associated fringe of other elemental processes, one is left no nearer to an understanding of the intrinsic meaning of meaning. In fact, C. K. Ogden once wrote a book bearing this very title, the meaning of meaning.

The significance of the foregoing arguments for visual work must be clear. In some quarters visual training is directed wholly and solely to the reorganization of the sensory and perceptual with little or no diagnostic or didactic effort to bring into harmonious alignment the re-shaped patterns of executant movement. In tachistoscopic work, for example, when we first train our observers to run off smoothly the motor processes of speech or writing which he is to use in reproducing seen figures, improvement is more rapid and more extensive. Failure in the motor phase may completely erase the prior impression. Instances can be multiplied.

Psychological Optics
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OPTOMETRIC EXTENSION PROGRAM

MOTOR THEORY: III

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Before we go farther we must be clear upon a few very important facts. In the studies on the ontogenesis of behavior in mammals up to a few weeks before birth there are no established paths in the central nervous system between the sense organs and the muscles. Afferent impulses pass by irradiation along whatever lines of low resistance are available at the moment. Movements are of the pattern of 'mass acts' (Coghill, Minkowski, Preyer). Both the sense organs and the muscles are sufficiently developed for individuated coordinated movements, but the central distribution mechanism is not yet ready. At this stage Minkowski showed that pressure on an eye ball is just as likely to produce a twitch of an arm, hand, leg, or toe "as it is to produce a movement which in any way refers to the eye."

Holt has pointed out that "because no connections between afferent, central and motor neurones are 'preformed,' or established by 'heredity,' the earliest movements of organisms are utterly random movements. The movements become biologically useful, significant or 'purposive' only very slowly. The human infant at birth exhibits mostly (but not entirely) random movements: and some trace of random movement can be detected at least as late as the tenth year, and indeed in a restricted and minuter sense, throughout life."

On stimulating the skin surface of a foetal limb "no isolated reflexes are seen but motor reactions which spread to the other limbs and to the head and trunk, and which are extremely variable." "In general, one may say that every part of the integument can serve as a point of stimulation for very various motor reactions, near or remote, and tending more or less to spread through the entire foetal organism." (Minkowski, 1924, 1925, 1928)

Any sense organ may thus acquire functional integration with any muscle.

Every afferent impulse originating in any sense organ as it proceeds through the central nervous system irradiates widely and alters the tonus of many groups of muscles. If the potential is raised in the head region, this exerts a gradient of inhibitory influence on all lower regions.

The above facts are the main reasons why the reflex-arc has been rejected as the basic physiological unit of behavior and why J. F. Fulton, for example, has insisted that we substitute for it the concept of movement patterns.

Consider, for example, the consequences of this fundamental conception of the relative roles of the sense organs, the brain and the effectors in the putting on of behavior systems of movements from the foetal stage to adulthood. It has been my privilege both to read and to listen to papers in the last two or three years on various phases of how we see (e.g. on acuity, accommodation and convergence, on stereoscopic vision, etc.) in which the entire argument was based on a doctrine of preformed nervous connections, corresponding points, and unit reflexes presumed and implied to be present from birth or very early age.

It must be clear to anyone who examines the evidence that our hope for the future of mankind depends largely upon the proper scientific understanding and proper development of early controls of how we fabricate through learning our individual behavior structures. Parker (1923) showed that the effector systems (muscles) become differentiated in the embryo before either the sense organs or the central distributor (the brain). "And this neglected priority,

phylogenetically and ontogenetically, of movement over stimulation, promises far-reaching consequences in both neurology and psychology" (Holt, 1930).

In order to understand what some of these consequences are let us look at the mechanism of how we learn 'reflex' movements. It is a temptation to begin with Bell and Magendie and trace the history of the concept of the 'reflex.' This has been done by Fearing, Locy and others and would take us much too far afield. Dewey in 1896 wrote a famous paper in the Psychological Review on the concept of the reflex as an organic circuit and not an arc. In it he pointed out that the first term in any 'reflex' is a set of adjustory accommodatory movements to place the sense organ in as near the optimal position for stimulation as possible; and that the so-called stimulus always lies inside and not outside the act. Sherrington reached the same position in 1909, as did Bok in 1917. The essence of the reflex as an organic circuit lies in one simple fact, curiously enough long overlooked, namely the role of the backstroke.

Suppose that we consider any muscle at the moment when an efferent impulse following a potential gradient to the outlet of least resistance (i.e. along the line of maximum conductivity) passes into the motor neurone of this muscle. As ions pass from the sole plates of the terminus of the motor nerve the muscle shortens or contracts. This is a twitch type or random or unorganized movement. But while the sense organ is still being excited, the sense organs (proprioceptors) in the muscle, in its tendons and in the joint surfaces are now being stimulated and these impulses are relayed back to the cord or central nervous system and there find outlet into the same contracting muscle. The backstroke, therefore, completes and unifies the organic circuit; it provides the maintaining stimuli which enables the movement to persist in time long after the initial or instigating stimulus has been withdrawn. After a few repetitions and after the consequences of the movement produce an interposition or change which is beneficial to the organism, a reflex circuit is established.

As a result of the backstroke muscle contractions tend to reinforce and perpetuate themselves. This is the 'circular reflex' which Sherrington, Magnus and others have described as the basis for 'postural tonus.' By this means the random and incoordinate movements, twistings and turnings of the foetus and of the infant are structured into patterns, or systems of movements, in crawling, standing, walking, talking, etc.

Holt, and later Hollingworth, have shown that in the foetus if an impulse reaches a flexor muscle of a finger it then presses against the palm. Pressure on the skin of the palm feeds back to further flexor contraction and after a few repetitions a reflex circuit is established. Afterward pressure on either palm or finger causes the finger to flex and to close down upon the object which caused the pressure. This is the origin of the 'grasping reflex,' usually well developed before birth. Many new born infants have to be taught the sucking 'reflex;' many acts such as speech require the development of aural controls. The failure of the congenitally deaf child to learn to speak, unless he has expert care and training, is a case in point.

It is thus clear that not only does the motor transform the sensory, but in the absence of an appropriate effector system set to go the 'sensory' impression must seek and find whatever inappropriate outlet it can. This is the chief reason why meaning is kinaesthesis; why the most powerful means of conveying straight, clear and simple meaning is by means of demonstration, gesture, posture, acting it out, mimesis.

A schematic diagram will help us to a better grasp of the essentials of what goes on in the process of forming the circular reflex. Two important omissions are made here deliberately at this stage in order to avoid confusing complication. The first is the role of the old nervous system and the smooth (white) muscles. Literally we should include the posture regulating mechanism of this system, since the diagrammatic effectors we shall use contain both red and white muscle cells. Second, we should include the very important account of the development and function of the behavior of half-centers (Sherrington.) Later we shall return to these. For the present let us look at Fig. I and consider how the burned child learns to avoid the candle flame.

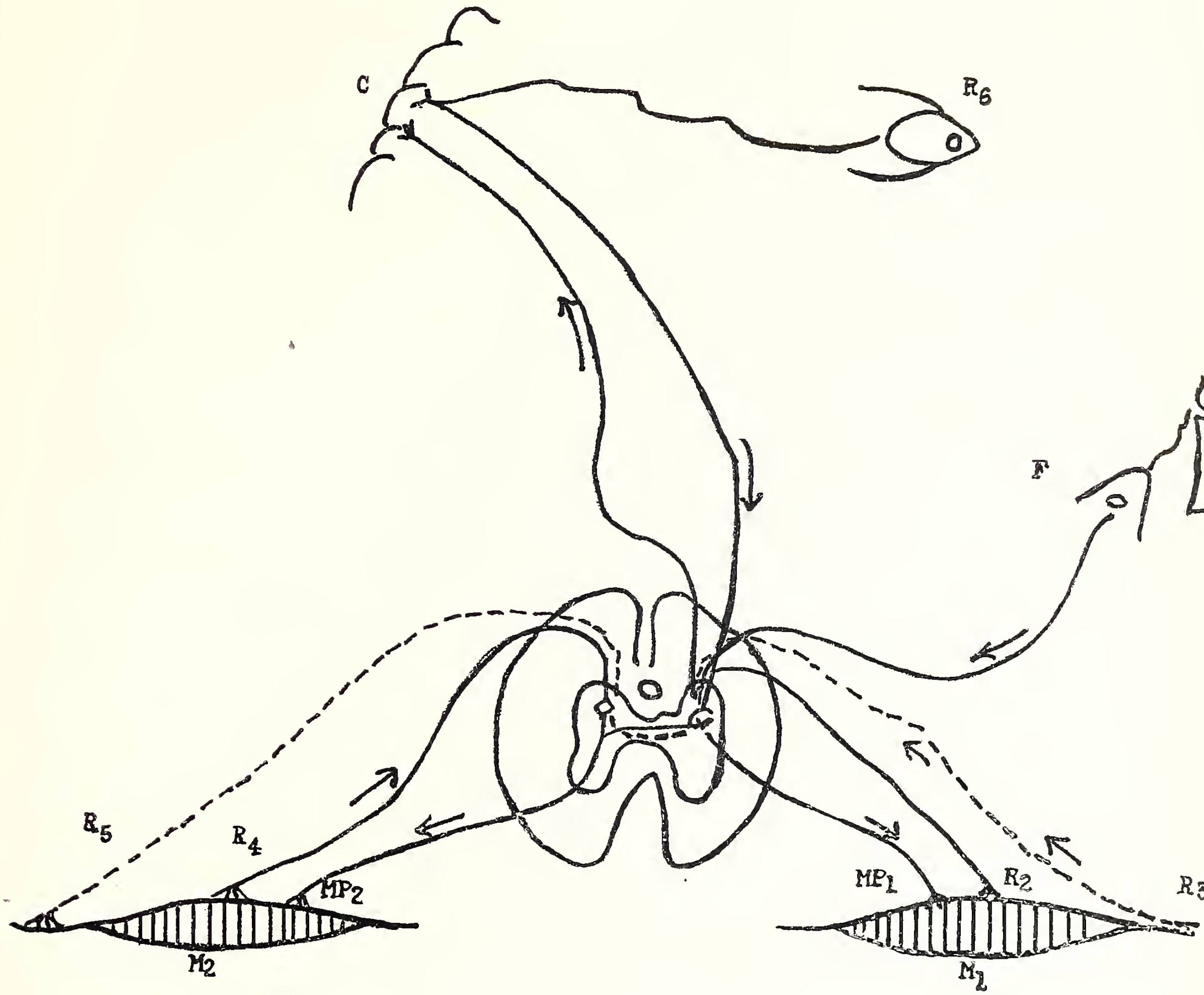

Fig. I

Note: The fact that M_1 and M_2 are taken as extensor and flexor Muscles and placed on opposite sides need not detract from the usefulness of this figure as a purely illustrative and schematic representation of a principle.

Fig. I represents a cross section of the spinal cord. A schematic single receptor in the finger F, and eye R_6, and two homologous but contralaterial muscles M, and M_2. Light from the candle falls upon the eye and the second, third, fifth and sixth pairs of cranial nerves energize muscles to turn the eyes and head to the postures of fixation, accommodation and convergence. But the child is a child - undeveloped in visual spatial localization so he resorts to the reality (for him) of the protopathic and better (for him) localizing movement of extending the arm, hand and finger to touch the pretty little light. Even in adulthood Tennyson's character contemplating his departed loved one longed

"O, for the touch of the vanished hand,
For the sound of the voice that is still."

Visual stimulation elicits the seeking, exploratory, precurrent random localizing movements, which terminate in contact with the flame. These exploratory movements are made by the contraction of M_1, an extensor. Impulses pass from the cortex C to motor point MP1 which starts contraction and in turn excites proprioceptors R_2 and R_3 in muscle and tendon which feed back to the relaying center in the anterior horn of the cord, completing the organic circuit. Note that after once the process is started R_2 and R_3 keep the muscle contracting and exploration continues until there is an end to the localizing movement. By the same token M_2 the flexor muscle or antagonist is comparatively active during this process, and the results is a tension movement, i.e. M_1 moves the limb against the brake-action of M_2.

At the moment of contact and the burn, the sudden intense volleys from F now pass through the commissural fibers to the opposite side where M_2 now more strongly contracts. Think of the schema as a group of simple electric circuits. If the M_1 circuit is sufficiently loaded any further current will flow to M_2 through motor point MP_2. Meyer and McDougall have called this "drainage by deflection" and regard the process as an example of Bernoulli's law of moving fluids.

As the extensor M_2 contracts more strongly the hand and finger move away from the flame, the head may be turned (and usually is) and the child runs screaming for protection.

The important series of reinforcing actions in the organic circuit at the lower cord level are all consummated while the distance receptor eyes are looking at the candle! Integration and foreshortening take place, through the instrumentality of the backstroke.

Pain, which Crile once called "representative injury," is heightened if the child is tense, fearful and is lessened if he can relax and start some other unrelated movement to prevent the fixation of the after-discharge phenomena, things of great neurological and psychological important, and again largely functions of the backstroke.

Our account is admittedly sketchy and oversimplified, but probably essentially in accord with at least part of the most important facts.

Two days later the child again sees a burning candle. Again eyes and head turn, the stage begins to be set for the localizing movement. But the movement system soon turns into those we class as caution, avoidance, etc. He retreats from the remembered noci-stimulation and reactance. The candle has come to mean do not touch.

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

MOTOR THEORY: IV

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In the phylogenesis as well as in the individual life history the first movements are of the form of mass acts. That is to say that such movements are diffused, not sharply directioned or coordinated, coarse, relatively slow, and certainly far from economical with respect to energy expenditure. The sensory instigation of such movements is likewise not sharply defined. Any strong or sudden excitation, or in fact any change in the total pattern of excitation, is adequate to start the general or more or less 'random' movements of approach or withdrawal. Sherrington, Magnus and others have shown that if the movements are of the approach type they may be reversed and transformed into the opposite type by such relatively slight changes as an increase or decrease in the stimulus intensity; or a similar effect can be produced by changes in the tonic or phasic activities of the muscles of any other part of the body system. Humphrey and others have shown that any change in any part of such a system can change the relations within the whole system. Any heightening of local activity or anything which conduces to the isolation of any part process or to the emphasis of any single function over others in the pattern results in consequences unfavorable biologically and psychologically to the organism. Indeed not only has it been a truism from time immemorial that "a house divided against itself cannot stand," but the essence of every serious attempt to understand organic behavior is reflected in the title of Sherrington's celebrated work on The Integrative Action of the Nervous System.

Adequate and successful living is only adequate and successful when the stream of successive movements maintain the organic unity and continuity of the living thing. From the first it is evident that neither the direction or magnitude of the movements constituting such systems are dependent upon specific sensory stimuli. There is no direct relation between changes in the intensity series in the impressions received by the sense organs and the kind, number or intensity of movements of the body. There is no direct dependence on any particular sense modality. The next thing the organism does is in very large measure set by the series of acts or movements which has just been consummated or by the projected demand of the future. There is no question but that the motor processes of the body set the stage for the sensory afferent excitations and transform them. Stimuli become instigators of acts only as they fit congruently into the prodromal state of the effector mechanisms at the moment.

The traditional mistake has been to seek for the determination of the nature, amount and kind of organic activity in the precise measurement of part of the sensory stimuli known to be active at any moment, and to assume a perfect psychophysical constancy between this and the subsequent movement system. While the modern knowledge of motor theory has shown that such a position is untenable we must not make an equally serious mistake by passing to the opposite extreme with the assumption that the afferent or sensory processes are of little or no importance. It is one of the objectives of this series of papers to show that all sensory functions belong inside and not outside of the framework of the action systems of living things; that sensory processes are, and must be, active processes or they are nothing: that the fundamental point of view in visual science gains nothing by an adherence to the traditional dualism of sensory and motor.

Let us look for a moment at some of the evidence which may be offered in support of such position. If we begin with the sim-

plest of all animal forms and trace the upward trend of evolution and differentiation the most primitive sense-receptor mechanism is, in the protozoal cell, bound up and undifferentiated from the effector mechanism which exhibits 'irritability.' There is no discoverable time differential between 'stimulation' and reactance. Energy of electrical, chemical, mechanical or other type adsorbs at the surface of the plasma membrane and there sets up changes in viscosity, surface tension, polarization, permeability. Movements which change the form and position of the cell ensue. If the 'stimulus' is radiant energy (light) and the animal form is developed enough so that the cell is a specialized and differentiated primitive 'eye," such as the tip of the medullary ray of the starfish, he moves forward or away from the source of the excitation until he achieves contact stimulation. If the motor response is inappropriate the population of starfishes is diminished by one. In any case the one and undisputable response which is the terminus of the series of energy events following the 'visual' stimulation is motor. It is most likely that at this stage the luminous part of the process is such that it responds also to the infra-red and the ultra violet and it is not at all unlikely that the real local process in the detector is one of temperature. In any case the whole process is classed as a tropism, both the qualitative and quantitative aspects of the energy impact upon a 'sensory' surface and the chain of events which follow through to the consummation. The animal moves to his sources of food and to shelter from his enemies and those things which start the process of katabolic degeneration. He does this and lives, he fails and dies.

It would be interesting to ask the animal as to what relative logical emphasis he places upon the so-called 'sensory' and the motor. I can forsee that we would receive a most clear and emphatic argument: No sensory stimulus is ever of any concern except as it is precurrent and prodromal to some useful movement.

"The essential feature of ..... tropisms, whether positive or negative, is that they are directional responses, and as such are the germ of that projicience which reaches its highest development in the visual sense of man" (Parsons).

In the lowest organisms as well as in ourselves the ability to correctly discriminate direction, distance, position, size, motion, etc., that is to say to preceive space relations, is of cardinal and fundamental importance. Our so-called refractive eye examinations almost without exception, on the other hand, deal primarily and basically with considerations of the physical, anatomical and geometric optical phases of seeing. Just to the extent that this is done can we judge them to be out of line with the soundest scientific tradition.

In the most primitive vertebrate animal - the Amphioxus - we find a most interesting morphological fact. His visual cells are situated within the central nervous system. And although this is a rare thing to find, the Amphioxus is not the only animal form in which this condition is found (Franz). Three types of cells are said to have visual functions in Amphioxus: (1) The anterior pigment spot, (2) Joseph's cells and (3) Hesse's cells. Only Hesse's cells are known to have visual functions. They have large cell bodies with one edge radially striated. This edge is turned toward a crescent shaped pigmented cell. A nerve fiber leaves the cell at the opposite side. These cells therefore have all the characteristics of receptor cells. They are situated ventral to, and on either side of, the medullary canal. On the left side the pigment cell is below, and in the ventral regions and on the right side it is above the receptor cell.

Such an arrangement is usually found in the simple eyes (ocelli) of the invertebrates. It provides for increased discrimination of the direction of a light source in addition to the very primitive appreciation of mere brightnesses. The left 'eyes' look upwards and the ventral and right 'eyes' look downwards but as the animal is asymmetrical and generally lies on its sides the 'eyes' practically look sideways and mostly to the side on which the mouth lies. Hesse's cells are most numerous in the head end. If the animal responds to light of threshold intensity 1 at the head end, the tail end was found to have a value of 1.5 and the middle of the body 25.

Sherrington has pointed out that here we have the beginning of the important con-

centration of the distance receptors at the top of the longitudinal axis of the body. "In the visual functions of this animal we have to do only with very primitive, essentially vital visual functions. The organs do not apprehend objects, but serve merely to regulate the posture of the body in relation to the light."

Thus the earliest function of vision in the lower vertebrates was to give direction to the brighter portion of the total visual field and to orient the body movements properly. Object and form vision come in at much later stages of evolutionary development. In man, it should not be forgotten, this primitive function of vision still operates, and most importantly so. Without it there would be no egocentric origin in the perception of space. Why did distance receptors ever develop? What is their function in animal and human taxonomy and ecology? Not only do they "induce anticipatory reactions which are precurrent to the final consummatory reactions" but they also furnish the possibility of a temporal delay between the sensory excitation and the motor response. With language or similar form of signaling the delayed response becomes possible, and the course of cephalization is given an immense forward step. Parsons points out that the sense modalities which give the maximum projicience, which make external reference possible and necessary, are vision (called 'glorified warm-spots'), hearing, ('glorified touch spots') and smell ('taste at a distance').

One further consideration is important for motor theory in considering the evolutionary series. The first and simplest of all the space forms comes from the skin. Long before there was any vision there was contact excitation and movements of thigmotropic or thigmotactic character. In the blind and in diurnal animals in low illumination we see the function of the cutaneous or haptic sense somewhat as it was functionally at the first. Now as locomotion increased in speed it became very necessary that limits were definitely set by reaction time and by the sharpness of visual discrimination at a distance. If the reaction time in any animal is .120 second and if the animal moves through space at a mile in 120 seconds he travels 44 feet per second and some 8 feet after he sees danger but before he can do anything to avoid it. Vision, because of the coefficients of reflectance and refraction of objects, is far superior to any other sense organ for the making of quick and accurate space discriminations. Visual organs having the highest anatomical development are found in the actively moving animals. This facts accords with the view, frequently stated, that "the chief functions of vision, biologically considered, are the control of the individual's movements, and the perception of movements in objects in the outer world." (Parsons).

Neither of these sets of functions are present at birth, except in the most limited sense. All related controls of movements have to be learned. And the behavior repertoire of the organism necessary for adequate and successful living is the primary determinant of all differentiations of the instigating system of sensory signals.

Psychological Optics
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MOTOR THEORY: V

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In previous papers of this series it was pointed out that the backstroke is the primary agent of integration. The backstroke is generally regarded as the sum total of all the afferent impulses which arise in the proprioceptors located in or about the muscles and glands activated in the consummation of any movement.

These impulses have their origin in time almost at the same instant that the excitations from the sense organs reach the cord. The fibers in the dorsal sensory roots branch in T-shaped cells so that the impulses pass not only up and down the cord to other levels, but immediately alter the tonus and start incipient movements in whatever effector organs are disposable to reactance at the moment. Thus in a very real sense we always react to our own responses as well as to some externally detected energy change picked up by one or more of the sense organs.

But we must also take an extended view, in the light of modern knowledge of the body systems, of events of primary importance which are non-nervous. It is entirely possible that the whole course of nerve conduction is dependent upon the production of chemical products at the synapses, such as acetylcholine, and that the scope of the truth in the oft heard statement that one responds "to a stimulus" becomes more and more limited. The chief role of the "stimulus" is its trigger like function. As Verworn pointed out long years ago a stimulus can only serve to heighten the rate of oxidation or accelerate a process already set to go. It can never instigate behavior de novo.

The excitability of the effectors is a function of the chemical mediators, just as truly as it is a function of the quality or intensity or any other property of sensory stimulation. For example in 1933 Cannon and Rosenblueth observed that among the substances classed as sympathins adrenine has two kinds of actions, excitatory and inhibitory. It acts as a stimulant to certain of the smooth muscle cells (in the walls of most blood vessels) and as an inhibitor of the smooth muscles in the intestinal walls. Some other substance or agent, therefore, present in the cells determines the reaction. In 1905 Langley observed this double action, and in 1932 Rosenblueth proposed that a substance A from the outside such as adrenine, or M a product within the cell unites in the cell with a hypothetical substance H, making a combination compound, AH or MH, which produces a response proportional to the concentration of the compound. Support for this view is found in the fact that sympathin which comes away from excited cells always has only excitatory effects on other cells in other parts of the organism. The blood stream is thus a chemical conductor and functionally at least must be regarded, with the nervous system, as part of the mechanism of behavior integration.

The hypothetical H substance is either an E substance (excitatory) or an I substance (inhibitory). When nerves are stimulated the combination becomes ME in a contracting and MI in a relaxing muscle.

Sympathin is defined as the chemical mediator of sympathetic nerve impulses, ME and MI, which in the cell induces contraction or relaxation, and which escaping from the active cell into the blood stream induces similar responses in remote organs controlled by the sympathetic system. It is not unlikely that the dilated pupils in myopia associated with diabetes may be a case in point. The liver is known upon stimulation to give off sympathin E having only excitatory effects and the gastro-intestinal

tract produces both E and I effects on remote organs.

The iris has two sets of smooth muscles, the radial and the circular. Only the radial fibers have the E substance. When adrenine is injected it forms AE to which these fibers respond to ME, as is the case when circulating ME is produced upon stimulation of the liver. The circular fibers have no E, so adrenine on reaching them has no effect. Adrenine active on the radiating fibers causes pupil dilation. ME substance however, brought from the liver could by bringing the missing E substance provide a stimulus which could act on the circular as well as the radiating fibers. The two sets of fibers would thus become antagonists. Now one and now the other would gain slight superiority and at times they might balance each other. These are precisely the effects observed in the experiments of Cannon and Rosenblueth in 1935 when they stimulated the hepatic nerves.

Is it not reasonable to assume that if such effect as complete reversal of function (such as the size of the eye opening) is not always due simply to the amount of light entering the eye, that also many retinal and cortical functions are similarly dependent upon the combined action of the non-nervous regulators as well as from purely optical and ocular considerations? There can be only one answer to this question. And since it must be an affirmative answer it must have telling consequences for those who support the tenets of what has been called "eyeball" optometry and ophthalmology.

Who can say, in the present state of our knowledge, just what is the terminus of any cycle of stimulation and reactance? When a visual form is closely regarded and we do something overt about it, such as naming, handling, etc., we know that covariant energy changes may be seen in wide reaches of the body systems. We know that changes within the retino-cortical-motor system may leave after-effects like hysteresis effects in living protoppasm which may and do profoundly influence subsequent processes in the perceiving of space, form, motion, size, distance, etc. (Köhler effects.) The process of seeing cannot be a mere matter of local interest. The physicist must go along with the chemist, the biologist, and the psychologist. The study of the motor aspect of seeing enforces such conclusion. We cannot seem to escape it.

When naming or handling responses follow visual form perception the backstroke from the skin, tendons, muscles, and from the articular surfaces of the joints of all parts of the body which change position as a sequent follows. These afferent backstroke impulses are more widespread and diffused than the sensory pattern of object perception. They form the field or ground or frame of reference for the percepts. They are non localizable. Not only are we unable to say at any instant where the origin of the kinaesthetic impulses is, but were we able to do so we would have no language mechanism to communicate them.

They serve however the vitally important function of empathy, of personal reference, of egocentric projicience of objects in space. It was the early recognition of this fact which led to the assertion that "vision alone is incapable of giving us accurate perceptions of space, form, position, distance .... etc." The ultimate consummating component is some effector process and the backstroke from it, together with the complex series of after-effects of an electrochemical nature which sets the mechanism in a definite way so far as future behavior is concerned. This fact, vital for all learning theory, is emphasized by the recognition of one further set of physiological facts. I refer to the function of sympathomimetic substances. These are chemical substances which mimic the action of impulses within the sympathetic and parasympathetic nervous systems. Bacq (1931-33) found, for example, in the aqueous humor of the dog and rabbit after excitation of the cervical sympathetic (but not the cat) a substance which had sympathomimetic action on isolated toad heart. Also when injected under the skin of the cat the hair stood erect. Sympathetic stimulation of a wide range of organs, heart, smooth muscles, glands, that are under autonomic control, produces a substance which is capable of mimicking <u>in other organs</u> the action of sympathetic impulses. It is not at present known whether sympathin results as a sort of secretion from the minute nerve terminals or is a product of the responding cells. The fact that it is there and that it operates

as we have indicated is undisputed. We can now better understand why it is psychologically true that meaning is kinaesthesis. Meanings derive from movements, from the executant acts and their consequences. We can understand and appreciate why any unitary movement is something more, something different from a mere series of muscle twitches.

It is a notable characteristic of a field structure that if the essential framework of a field is active it can redintegrate the whole. This fact is of cardinal importance. In visual training we observe that the trained perceiver exemplifies what Tolman has called the law of the recession of the stimulus. The more advanced the learning process the less important is the stimulus, the less necessary it is to have it bright, sharp, clear, enduring. The greater the skill of a function the more it is true that the stimulus sets the process in motion and it becomes more and more self-maintaining. Without such fact high levels of virtuosity would be unattainable. Without such mechanism how could a concert pianist play a two hour concerto from 'memory'? How could an expert tennis player readjust his movements after the ball sails over the net?

It is because of the backward imposition upon the receptor and conductor system of predetermination of movement by the effector organs themselves that we see what we are set to see, what we hope, fear or want to see. It is psychologically true that when we observe the repeated attempts of a subject to draw or reproduce a form shown to him again and again by the method of serial reproduction often his first drawing will be partial, incomplete and erroneous. His second will more and more tend to a reproduction of <u>what he did</u> in the first case than <u>what he saw</u> on the second exposure.

It took many years of research and theory for us to discover that the basic attributes of perception and those of skilled movements are one and the same. This is a debt we owe to a number of scholars, Beaunis, Richer, Stetson, Dodge, Mussatti, Metzger, Köhler, and many others. It is one of the justifications for the fact that improving the total coordinations of children with visual anomalies improves them. It is one of the good reasons why we must take an extended view of the scope of optometry and ophthalmology. Neither can limit its interest or operations to the eye alone.

Psychological Optics
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MOTOR THEORY: VI

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The history of our various ways of regarding the physical world and its position in the cosmos is of interest to us in connection with motor theory. Prior to Copernicus, scholars almost universally operated upon the assumption that the earth was the center of the universe. In 1543 Nicholas Copernicus published a treatise on the rotation and revolution of the heavenly bodies which advanced the radically new heliocentric view of the planetary system, and slowly but none the less surely revolutionized the science of astronomy.

Not only this but ideas began to stir in the direction of a newer and different way of the treatment of man's own position in nature. It took us three hundred years to reach the stage where equally revolutionary discoveries produced the protoplasm doctrine. And until approximately the close of our own Civil war the histology and cytoarchitecture of our bodies was truly a dark continent.

It was almost a third of a century later (1892) that Cajal and simultaneously William His discovered the neurone. So for only a little more than a half century have we had the slightest notion of the structural design of the central nervous system. Likewise almost all the facts about the nature of nerve conduction, what it does, how it works, and more important still what it does not do, date from the close of the first World War, about twenty-five years ago.

It is hoped that this bit of historical perspective will not be lost sight of when we try to construct a way - we hope a new and better way - of regarding the act of seeing. The moment that we admit the last phrase in the previous sentence, that is that seeing is an act, we do essentially the same thing Copernicus and many other like him have done: We force a change in point of view, in method and in the basic definition of problem and interpretations. The utterly passive analogy of the camera or copying of external energy patterns by retinas and brain simply belongs to a past and closed chapter in the history of vision. But what the lawyers call the 'dead hand' is still strongly operating. Some people whose training should prevent them from so doing talk and act about seeing as if they were still living about 1840. Any one of us makes this mistake when we think, talk or act about any visual function in isolation, that is without regard for the fact that seeing is an intra and extra organic system operating and existing only within and dependent upon other systems. We make this mistake when we talk about visual form and visual space in the terms of naive nativism and of functional "explanation" of the processes solely in terms of geometric optics and the anatomy of the cortex. Only recently I read such an account of how we see in the third dimension and how these functions become distorted; chapters written by a dead hand working through its authors live brain and muscles. We make this mistake when we, through ignorance or laziness or both, fail to realize that the impression received at any instant by a sense organ is only one small fraction of the set of factors which determine the final adjustory or consummatory movement. The number of ways in which we can be wrong seems to be legion.

Last month we emphasized the well known fact that what muscles contract and what glands work their chemistry is as much a matter of non-nervous as it is of nerve conduction instigation. We discussed briefly the functions of sympathin and of sympathomimetic substances. In this paper we shall go a step farther and consider the pace setters and their functions.

But first let us return to the schematic diagram shown in a previous paper (Vol.7

No. 3). This diagram was used with certain misgivings. Mainly I sought only to show the essential role played by the proprioceptors in the constitution of the organic circuit or homeodetic circuit (Cannon). This was the basis of the expanded concept of the 'reflex' and the failure to recognize it earlier was certainly the basis for the abandoning of the 'reflex' as the unit of movement and the substitution of the concept of the unitary movement pattern (Fulton).

The main difficulty in presenting a diagram of this kind is that it over-simplifies things and very often leads some people to draw wrong conclusions about the mechanism of the control of movements. Most of the opposition to the transforming influence of activation, practice or training comes from those whose previous training has been rigidly physical and from the standpoint of topographic anatomy. This arises out of the mistaken notion that 'learning' reduces simply to the matter of 'bahnung', trail blazing in the central nervous system or the lowering of synaptic resistences to form highly specific conduction paths. The work of K. S. Lashley (Brain Mechanisms and Intelligence, Chicago U. Press, 1929) concluded that "the capacity to learn .... is dependent upon the amount of functional cortical tissue and not upon its anatomical specialization." Koffka (The Growth of the Mind, pp. 76-86) has shwon that when infants and young children learn to fixate upon a point source within the visual field and control the movements of the eyes, there is no possible way to account for the complex system of pursuit and stationary fixation postures and movements if one seeks to make discrete retinal points the determiners of the order and magnitudes of the contractions of the extrinsics. "Instead the hypothesis is advanced that the specific pattern of the seen-object itself regulates the movements of the eyes." "The optical sensorium and motorium cannot be regarded as two independent pieces of apparatus, since for many types of performance they constitute a <u>unitary organ</u> -- a physical system -- within which separate organic parts may react upon other parts." Whether one agrees with this hypothesis or prefers some other is relatively unimportant. It is important however to realize that almost all of our acts run a course in time; that some mechanism of integration is utterly necessary, and that the kinaesthetics, the backstroke from each successive phase of any movement series can fulfill this stipulation.

It is the contention of the writer that the backstroke is the mechanism which <u>extends</u> the visual process to include the effectors, particularly the apparatus of speech and manipulatory hand, arm and leg movements and postures. In so doing it establishes the perceiver's empathic point of vantage and permits him to orient himself and his world of seen things with the result that position, form, spatial extent, distance, depth, movement, etc., become established. This is of cardinal importance. If we think of the backstroke not as a mere twitch phenomenon but as a serial-movement report and if we think of it then as something analogous to a melody rather than a single tone or series of unrelated single tones, then we can see more clearly the reason for the assertion that "the common denominator of all meanings is kinaesthesis" (Titchener). And if further we assume the recurrence or recall of the image or after-effect of such backstroke pattern we can understand how it becomes dynamogenic, i.e., the integrating and instigating agent of perceptual patterns. This is exactly that thing shown for example in the work of Stetson and others on the analysis of skilled movements. When the act ceased to be a tension movement and took on the ballistic or skillful characteristics, the instigating sensory stimulus <u>and the muscle contraction</u> threw the limb into a percussion like stroke now controlled by its own movement produced excitations. Both the 'stimulus' and the power stroke of the muscle lasted but about 1/25 second, only a fraction of the total duration of the movement.

Likewise it is of interest to recall that in the experiments on the conditioning of responses extinction always follows upon the failure to complete the consummatory act. If a dog salivates at the sound of a tone of 256 cycles the tone quickly loses its signal potency if there is no feeding. Behavior is a continuum of movements, not an aggregation of separate, more or less independent segmental parts. The stage is always set for what is to follow in time in terms of what has gone before, with both things regarded as belonging to a still longer section kinetic system.

Not only do the proprioceptors and the chemical conductors cooperate in the con-

trol of movements but the effectors themselves impose backward upon the efferent conductors, and perhaps even back to the sense organs themselves a characteristic phase or periodicity of excitation and conduction. This was shown by Landacre many years ago in his studies of the action of the phrenic nerve and the muscles of the diaphragm in breathing. Electrical stimulation of the intact nerve could only produce contractions up to a certain critical frequency beyond which there was overloading and blocking. When the nerve was separated from the effector the conduction rate following faradic shocks was greatly augmented.

Lillie, Osterhout and later Hoagland have studied the action of what are known as pacemakers or pacesetters. These have to do with time, temperature and electrochemical effects. Piper, for example, showed that the neck muscle of a tortoise has a bio-electric rhythm which is proportional to the temperature. The following figures are a sample of the temperature effect:

Temperature C°	Number of Waves
7	15
12	19-20
18	29
24	38
28	44
32	51
36	56

It has been shown by Osterhout that electrical resistence in simple plant or animal cells is an accurate index of vitality. In strong sodium chloride solution such a cell lowers resistence until it dies. The equation of the rate of change against time has been determined. The acceleration of death can be inhibited by adding calcium chloride to the solution until an optimum ratio of the two salts is found in which the inhibition of the death process is maximal.

Osterhout concluded that recovery from injury is not the converse of any reaction which produces injury. Normal metabolism is a balance of electro-chemical reactions, injury and recovery differing in the relative speeds at which the sequence of processes takes place. Next month we shall continue the consideration of pacesetters from this point.

Psychological Optics

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MOTOR THEORY: VII

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Our attempt, in these papers, to present some fair representation of the biological and psychological mechanisms involved in the simple acts of organisms leaves one with mixed feelings. One of these is the feeling that it is not easy in the limited space of the papers to be as full and complete and as clear as one should like. Another is the feeling that no matter how closely one may approximate such an ideal, the fact stands that most of the basic understanding of phenomenal experience would still have to stand as the target for research. We may set in apposition some of the pieces of the jigsaw puzzle. We may form some notions of how the final picture is likely to look. But we must, too, be mindful of the fact that we are still a long way from being able to take the step from what we know about light, sense organs, the central distributors, the effectors, the backstroke and the nonnervous or electrochemical conductors to the simple story of how we see objects, space relations, forms, movements, colors, contrasts, etc.

Nonetheless there are a number of physical facts which we must understand, and reckon with, if we are to keep our thinking in the spirit of the times.

One of these is the fact that 'resting' states are not states of rest or inactivity. Thirty-five years ago Jacques Loeb pointed out that life processes depend upon a series of interrelated chemical reactions which proceed at normal rates which bear definite relations to one another.

If a change occurs, say in temperature, the relative rates may change and these in turn become the determinants of the amounts, rates and kinds of processes called excitation, injury, recovery, growth, differentiation, dedifferentiation and even death. There is always a change in pattern or field relations. If so a "minor" change in one portion may become the determinant of a major change in some other region of the field, even remote from the locus of the primary influence.

The speed of many chemical reactions bears a definite relation to the local temperature. This is van't Hoff's law, usually expressed as the Q10 coefficient. If Q10 = 2, this is another way of saying that with each increase of 10° of temperature the speed or frequency of alternation of a reaction will double. In the dozen years following 1921 Professor R. S. Lillie showed that with a piece of bright clean steel wire and a tube containing an appropriate concentration of nitric acid, he could duplicate most of the behavior characteristics of a living nerve: rhythmicity, refractory phase, transmission, recovery of irritability, etc.

Temperature, he showed, greatly influences the duration of the recovery period; less by half the rate of propagation of the 'conduction' along the wire. When the wire was suspended in the acid (after passivation in stronger fuming nitric acid) on being touched by a zinc sliver just below the surface, the wire responded by a 'wave of oxidation', turning rapidly black along its length, the advancing front emitting active small gas bubbles. After a few seconds the wire repassivates -- acquires again the velvety brown coat and is in the active or excitable phase of its rhythm. "By locally limiting diffusion, the acid next to the wire in this region is apparently reduced in concentration after the first response below the critical value necessary to form the repassivating oxide layer. The continuous reaction is then able to act as a sort of "pacemaker", initiating in the wire immersed in the stirred acid rhythms of activity at frequencies depending primarily upon the rate of recovery of the wire (Hoagland). The speed and range of influence of the pacesetting region of the wire was seen as analogous to that observed in the stimulated receptor, which also acts as a pacemaker as do the receptors found in the executant moter apparatus -- the muscles, tendons, skin, joints and glands.

Here the frequencies of the afferent volleys vary with the stimulus impact intensities. The frequencies may be largely the determiners of the conductors thrown into synergetic activation. Since such seems to be accepted as true, we can see that activation by exercise or training of a particular portion of the visual field is a perfectly sound and logical means of creating a change in the contours of the field.

Suppose, however, that, instead of a system set in a rhythmic pattern of reactance to single stimuli by means of pacesetters or master reactions, we apply continuous and constant stimulation to such a system.

If we do this to a surface containing numbers of receptor cells, some of them will be activated and will fire afferent volleys only at and for a few milliseconds after the onset of stimulation. Others will only fire at the cessation of the stimulus. About one in four or five will fire continuously during the period of active receptor excitation. When these afferent volleys are examined after amplification and photographing (Adrian, Hartline and others) there is observed a gradual diminution of the number or frequency of the spikes or volleys. If continued sufficiently and with no variation in intensity a point is reached where adaptation occurs. Nafe showed that when a weight was carefully lowered upon the leg just above the knee, his observers ceased to report pressure when there was no further micro-compression of the tissues. Fulton has pointed out that differences in intensities of stimulation of a single end organ can only be communicated by differing rates of discharge of afferent volleys. A rapidly adapting sense organ will be a poor recorder of intensity, because the rate will be a function of the duration rather than of the intensity of excitation. Muscle spindles and pressure receptors adapt very little and "hence whiledischarging continuously -- will be sensitive to slight changes of intensity and will signal such. Touch receptors, being rapidly adapting, are poor for signaling grades of intensity" (Fulton). Matthews in 1931 showed that the proprioceptors in the muscle spindles adapt very slowly, if at all. This fact, coupled with the fact, shown by Hoagland, that in a chain of reactions the slowest function is the pacesetter, indicates clearly that we must conclude that our mechanism of the backstroke adapts least. It is therefore the perfect means of supplying the agency of integration of energy patterns from the sense organs; for extending these processes in time, even long after the cessation or removal of the stimulus; and for serving as the ground or space lattice upon which figural organization can proceed.

These are important considerations for vision. They help us to see why, for example, we should, and do get pronounced alteration of basic visual functions when the posture of an important segment (head, neck, back) of the body is displaced or when the total space projicience with respect to egocentric localization is disrupted by the removal of the backstroke from the antigravity musculature. Visual space is thus perhaps more muscular space than it is anything optical or ocular. Likewise it can be shown that our basic sense of time is likely related to chemical pacesetters in the central nervous system.

Physiologically, a pacesetter is a localized continuous chemical change which reexcites the conducting fiber when it recovers or regains irritability after the refractory period following the transmission of the previous impulse. It is generally regarded as fact that the cells comprising the central nervous system are 'spontaneously' active even though there are no afferent impulses present.

Nuclei or groups of cells may discharge nerve impulses at regular frequencies over efferent pathways. It is the view of several leading investigators that the main function of the afferent impulses from the sense organs is to enhance or to inhibit such continuously active units.

Such a view immediately forces the student of visual problems to give the requisite and proper emphasis to what Purdy, Nuel, Michotte and others have called the motor transformation of the sensory. Sense organs have no imperious power to dictate to muscle groups the order, sequence or magnitude of response. The brain cannot possibly dictate to a muscle group the command to contract or relax now. Nerve supply grafted from an entirely different source

proves that fact. And in passing it may be well for those who express doubt as to the validity of Marina's famous experiments on the surgical reversal of the extrinsic eye muscles to reflect upon these facts. When the monkey's eye muscles were reversed (i.e. the internal and external recti) the eyes should, upon the demand for convergent fixation, diverge. Instead the eyes "tracked" perfectly!

It is hoped that, too, these basic facts as to the backward imposition upon the central distributors and the sense organs of the effectors determining the movement patterns to any kind of stimulation will not be disregarded in dealing with the problems of phorias and tropias, of binocular space (depth and distance) and of the concepts of the mechanism of the functions of accommodation and convergence. It must be clear, for instance, that any attempt at the orthoptic reorganization of a visual field by the mere control of peripheral stimulation of the eyes alone cannot be sound and successful.

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

MOTOR THEORY: VIII

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Things, whether chairs, rocks, dogs, or planets, are defined in terms of their properties or attributes. One of these is extensity. Every existent thing is protense, that is it exists in time; it had a beginning sometime in the past, and it has come along to the present. Extensity is the spatial attribute of things. They have some position in space.

Space is an abstract word. We find it useful as a sort of symbol for the fact that our perceptual lives - i.e. our 'real' or phenomenal lives of experience - are set in a framework of the relations between objects of attributive extensity.

From very early times there has been a lack of agreement as to the truth of this last sentence - that is controversy as to whether space is a receptacle for things or an attribute of them. Newton, for instance, held that space is a real receptacle, intrinsically void. Descartes said space is the essence of bodily substance, and Spinoza and other philosophers held that it is an attribute of substance.

Bishop Berkeley, the author in 1709 of the famous "Essay Toward a New Theory of Vision," regarded space as a psychological construction resulting from the "coordination of senses, particularly of sight and motion." Kant and his followers had still another view. Euclid, the geometer, said that we infer it from our incomplete experiences but that it has three dimensions, each unlimited in extent, and that it has the same properties in all its parts.

Gottschaldt, the genetic psychologist, holds that no child ever does anything of any greater importance than to form his space world. This, along with physical growth and development, is the major concern of his first seven years.

There is no question as to the importance of the problem, in adult life as well. There can be little doubt, either, but that space can never be purely sensory. Its essence is movement (kinaesthesis). If we agree with von Hornbostel in his insistence upon the doctrine of the unity of the senses, and we realize the prime distinction that in physics (Newtonian) there is but one space, attributively always the same, and that psychologically there are many spaces, in the terms of any description of our common everyday experiences, then we have an unimpeachable justification for the importance of motor theory as an important term in every visual equation.

If we can accept the foregoing, and you can be assured that many highly competent students of the problems of sensory and motor functions do, then we must dissent from those who take the curious position that a child, for example, who three months ago showed a marked measured space anisotropy (20/90 acuity at far, 12 eso. at far, rivalry rate 11, stereopsis threshold 950 seconds, third degree fusion lowest tenth percentile, reading indices of speed and comprehension low fifth of his grade,) and who today is comfortably within the normal range of these functions, is gaining rapidly in school, sees clearly and singly at far without the necessity of lens help, still has his ametropia! He has, the advocates of this kind of view insist, "merely learned to interpret a blur!"

It is easy to prove that this statement cannot be defended by its supporters. If, for example, acuity training which changes an observer from index 0.7 to index 1.4 (i.e. at first he can resolve standard 6 meter König bars at 4.2 meters, later at 8.4 meters) still leaves him seeing the bars blurred we can prove or disprove the point by a method used by one of my students in his study for the Master's degree, Mr. Roland Hudson, "A Comparison of Two Methods for Measuring the Resolving Power of the Eye," 1939.

Hudson used an instrument designed by the late Professor A. P. Weiss and described by him in the Journal of Experimental Psychology, 1917, 2, 106-113. This is a Focal Variator. A lens system enables one to vary any target from complete blur to maximum sharpness, keeping size, intensity, accommodation and convergence constant. Hudson

measured the vernier distance into the blur (1) of the minimum separable and (2) the first appearance of sharp angular contours, on his observers before training and after training both on McFadden's type of apparatus and on the Variator. In every case without exception the range of the minimum separable and the attainment of sharp contour (constant separable) shortened greatly and moved farther away from the eye.

For three typical subjects the minimum separable moved from 862 to 528 scale units and the constant separable from 1142 to 722 units.

To say that these observers still blurred but saw clearly is a meaninglessly statement, contradictory to the facts.

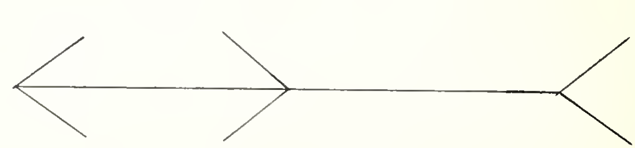
Let us take an instance of another sort. Here is a child of equivalent age - say 12 years. From birth both lenses have been opaque. He is made aphakic and fitted with lenses. He learns a new set of space concepts and a new repertoire of movements in space. Should we, by the same logic, say <u>this</u> child is still blind?

In my April and May papers, I pointed out that the kinaesthetics (backstroke) are the least adaptable segments of the unit organic circuit and that they are the mechanisms which <u>extend</u> vision to include the effectors, particularly the apparatus of speech and manipulatory movements of the limbs. This conclusion derives in part from two doctoral dissertations in my laboratory, one by Dr. W. C. Schwarzbek, and one by Dr. Otis D. Knight. Both men showed, from two years continuous experimentation directed at carrying the training of visual form perception to the utmost limit, that <u>visual</u> perception in the highest skilled observer <u>becomes essentially a nonvisual process.</u> In the early novice stages of form perception the dependence of speech or hand reproductive movements on the visual impression is maximal. But from the very first if a simple form is shown and it is reproduced incorrectly as to size, relative position of parts, etc., his subsequent reproductions will resemble more the pattern of his movements revealed in his first and subsequent drawing and less the characteristics of the purely visual shape. He <u>achieves form</u> finally by a transformation of the sensory - cerebro - motor field and in this reconstruction the role played by the <u>movements</u> he makes is paramount. F. C. Bartlett, in England, found the same thing, as have several other experimental psychologists who have studied the problem.

There have been numerous efforts to teach people a virtuous or highly skillful golf stroke by means of having them watch slow motion pictures of experts making the strokes. Has anyone ever learned the simple but inordinately difficult unitary movement that way?

In fact, theory and the purely sensory aspects of a skilled movement, introduced too early in the learning or practice series, may actually hamper and retard progress. (Renshaw, S., Pursuitmeter Learning Under Three Types of Instruction, J. of General Psychol. 1928, <u>I</u>, 360-367) We simply must realize the fact that even complex perceptual functions become foreshortened, condensed, simplified with practice and use. Like Köhler's figural after-effects of sensory impressions there is a motor transformation of the regions of the nervous and chemical systems involved leaving them altered in some way with respect to subsequent activation, and more important still, the influence of the afferent proprioceptive impulses (backstroke) more than likely creates a field extending beyond its own contours capable of altering the course of new patterns of excitation arriving in the range of influence of this field.

This is, of course, a very modern problem and much research lies ahead. But for those inclined to shout in criticism that it is a construction of some mysterious master faculty in the brain, let them ponder the mechanism of fact, reported by Professor Köhler, recent recipient of the Warren medal in Experimental Psychology for his work on figural after-effects, that within thirty minutes by using 5 second impression periods he was able to abolish completely the effect known as the Müller-Lyer illusion. This is a figure like this:



In it the lengths of AB and BC are adjusted to the point of equality. The illusion is known to persist in spite of any amount of knowledge of its history, underlying principles, etc.

History will probably record as a curious and difficult to understand paradox the period of the Nineteen Hundred Forties as one in which good and well trained men in learned professions dealing with the functions of the sense organs suffered from a crippling form of short sightedness in their reluctance, aversion and even hatred of the proposal to regard vision, for example, as a process going beyond the physical and functional limits of the sense organ.

They cannot reconcile themselves to accept the often demonstrated scientific fact that function alters structure at least as often and as potently as does structure alter function. In fact were a child to develop and differentiate through the egg, blastula, gastrula, embryo and infant stages immobilized throughout, what would he be like, mentally and physically, assuming that he lived? How does his movement system arise? Is the evidence of Harmon and his co-workers to be disregarded when he shows that faulty posture, in the early school years, may and does alter the degrees of freedom of body and limb movements, axes of growth and form, the pattern of dentition and the shape of the face? Many of the muscles of the body are laid down, developed and differentiated and ready to function well in advance of innervation from the central nervous system. They respond at first only locally as 'parts' or subsystems which later become integrated as the mass act stage (Minkowski, Coghill, Weiss) is replaced by the individuation of movements. The muscle twitches become movements.

Man's ultimate superiority over his fellow living creatures is attributed to the process of cephalization - the evolution and development of the new brain. There is now little doubt that this process is paralleled by his development of manipulation - of tool designing and using devices. We need not engage in the fruitless controversy as to which "caused" the other. Science is never interested in "causes". Its task is to specify the conditions under which things take place. Causation is a problem for teleology, not for science.

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

MOTOR THEORY: IX

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Last month we called attention to the fact that when the process of visual form perception is carried to extended limits through training (Knight) the role of the stimulus becomes reduced to a minimum. Its main function is the incubus which touches off a 'determining tendency' or a 'meaning tendency'. These two terms are historically used in psychology to designate the early precurrent stage of set, attitude or predisposition to movement of a specific serial kind which is the characteristic of the 'voluntary' type of movement.

In the earliest stages of any perceptual act the new impression conduces to the search for meaning, or to the approximative and corrective series of events which leads to the best possible resolution of the disturbed equilibrium. Sensory stimulation upsets the equilibrium, motor processes restore it. It is quite doubtful if ever there is an absolute return to the status quo. Every consummatory act serves not only to re-establish a tolerable equilibrium state, but it leaves mnemic traces which, on repetition of the stimulus impression itself or something identified as sufficiently similar to the original, changes its course. This is what Ebbinghaus, Meyer and others called sensory condensation or foreshortening.

In a similar fashion the repeating of a series of movements which comprise a consummatory act leads to the form of telescoping or foreshortening called motor condensation. The movements become fewer and simpler as skill accrues. The active contracting phase of the effectors themselves reduces to a minimum. The proprioceptive, movement produced sensory signals now come to extend the process, both in space and time. Meaning is thus so largely kinesthetic because the end always tends to regress within the means to the end. The true role of all sensory functions thus eventually becomes one of instigating some effective series of adjustory movements. The time required for them to do this becomes less and less.

Except in the most novel instances, as Dewey pointed out in his famous paper on the concept of the reflex as early as 1896, sensory stimulation always lies inside and not outside the act. This is but another way of saying the well known fact that when light enters the eye at any point eccentric to the line of sight <u>movements</u> of focus and postural alignment precede the cognitive identification of the object seen. The first term in seeing is a complex series of movements, not sensory stimulation. Every sense organ is arranged with such accessory motor mechanisms. In hearing the stapedius and tensor tympanum adjust the drum and the chain of ossicles. In taste Scofield showed that when the tongue is painted with a topical anesthetic, the first function to be lost is motility and as this procedes there is a consequential heightening of the gustatory thresholds. In fact it is not even necessary, as Scofield showed, to anesthetize the tongue. When this organ is immobilized, by a dental tongue elevator for instance, the same raising of the thresholds follows.

It is really difficult to understand the position taken by some good folks who seem to believe that the giving of proper and proportionate emphasis to the motor aspect of life and experience is detrimental to the position of dignity of the sense organs. The eye is a never ending source of reverent awe. It does things which can only claim our wonder. With Walls, as we examine its evolution through the long past, the wonder grows. Yet with all the fineness of its mechanisms it is a means to an end. It is one essential portion of a much larger functional and structural unity. It does what it does because it works with other portions of that essential unity. When we take away from it the part of the seeing act contributed by the effector system of the body there is nothing visual left. In the similar field of hearing the expert linguist isn't much concerned as to whether analogic change in language forms is mediated by a cochlea which functions as

a resonance or a nonresonance, a place or a frequency mechanism. Are vowel sounds pure single frequencies or are they polyphonic? He doesn't care. His concern with such matters is, if I am not mistaken, largely if not wholly in the preceptual-motor terminus of aural stimulation. Perhaps the most perfect language of a purely visual type was the old silent movie, and this was entirely a language of gesture, of posture, of mimesis. Naturally to understand spoken language we need good ears. We also need clear speakers, and it helps considerably if beyond the ears there are certain residua of some considerable work in mastering the vocabulary, the syntax, etc., which goes to make up what may be designated as one's literacy. Certainly no one would deny for a single instant the need for good sense organs. The issue turns on how we answer the question. What is a good sense organ?

The late Professor Raymond Dodge was certainly well qualified to speak on this problem of the role of the sensory functions in human behavior. He said "---there are, in adult human behavior at least, no pure habitual responses uncontaminated by reaction set and the epicritic elaboration of the sensory data. The degree of that elaboration is limited only by the intellectual resources of the organism and the time that is available before the response to one change in situation passes into response to another."

This is what Titchener meant when he said that we always perceive more than is furnished by the stimulus. Seeing is never a copying process. The sensory impression is a trigger like thing. It is, in adult life certainly, always set in a framework structured from the results of what we have done to us. The burned child dreads the fire. Dreads means that fire much earlier in time sets in motion the complex fabric of meaning and movement tendencies of avoidance and escape. Anatomically the eye is an adult eye by the age of about four years. What of the four year old's discriminations of the third dimension, of form, of motion, size, color, position, etc.? Why are these things not full grown too, if the things which happen at or in the retina are the decisive determinants of what we see?

Dodge further points out that "our picture of human adjustment is not a mosaic of conflicting reflexes, habits, and voluntary acts or a succession of separate responses under these various categories" but rather, he says, it is "a dynamic continuum, - a sort of spiral process with a comparatively simple front of overt reaction at any given moment with a highly complex background."

It is probable that present stimulus patterns superpose "upon the remains of consummated responses to past stimuli by which they are inhibited, reinforced, or qualitatively modified." The protopraxis or forerunners of acts are only in part the stimulus impressions; for these are always transformed by the role which memory plays in conduct. There must be some agent of organization and unification otherwise my eyes looking at the vista of the campus buildings, trees, cars, people would be a chaotic patchwork of competing energy masses whose only terminal result would be disjunction. But that is not how I see. I see coherently. I can shift from "seeing the scene" to the minute examination of the relative structure of the barks of two adjacent trees. I can actively do something about my visual field. My eyes alone are passive. They take what comes to them. Only in a limited sense can field structuring be regarded as a retinal process.

Space perception, said J. P. Nuel in 1904, is ultimately determined by motor orientation tendencies. Peterson reached the same conclusion in his studies on the problem of how we can localize a point stimulated on the skin. The local sign of Lotze became the orientation tendency of Peterson. Since localization is to the skin what projection is to vision. It seems that we may take the products of movements as a basic agent of organization in any sense modality.

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MOTOR THEORY: X

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There are a number of good reasons why we must be interested in the mechanism of voluntary acts as related to the act of seeing. When a pattern of light starts the chain of events in the eye which results in the perception, naming or classifying of the instigating agent, this may terminate the process and mark the shift to the next episode in the continuum of experience. On the other hand it may merely present a problem of what to do about it and thus instigate the search for meaning or the necessity to select and pursue one course of action rather than any one of several alternatives.

In any case every event is preliminary or prodromal to movement. The stimulus is effective if it is consonant and conformable to the set, attitude or predisposition which is already there in the reacting system. And this as we have tried to show in previous papers is a highly complex matter. Set can be either or both a hysteresis effect in the nervous tissue or a maintained posture.

It is a commonplace observation that decisions made just after receiving some extra good news are tinged with an unaccustomed generosity or tolerance. Conversely, the 'halo' effect in adversity or defeat may negative perceptual judgments which otherwise may pass.

Craving, longing, intention, desire, wish, will are terms which have a common characteristic: an "inherent tendency to pass beyond themselves and become something different". The essential agent which brings about the state of something different is some type of act. Conation is the term traditionally used to designate the direction of events or processes toward a goal or end.

Not only is the forward reference of any present stimulus-reactance series projected as a unified series toward some desired end or objective, but Washburn has pointed out (Movement and Mental Imagery, p. 47) that "the peculiar motor effect of a stimulus on the organism as a whole may be the basis of the recall of mental imagery." "Wherever in a movement system it is possible for an old associative disposition, based on much repetition, to take the place of a new one whose strength lies rather in recency than in repetition, the substitution occurs" (p. 147). Abel has shown that this law explains the illusion of Aristotle, when a pencil is held between two crossed fingers. The tentative movements, she says, belonging to two pencils are set up as a result of tactual stimulation even though a unitary response to the visual stimulation is made. "The associative dispositions stirred up by the sight of the single pencil are not able to withstand the old dispositions connected for life with the stimulation of two points on the skin that are not normally reached by a single object at the same time."

Not only Washburn but Bartlett and others have shown that the same law holds for recall. Memory images tend to alter in the direction of the usual and normal, losing their particular and specifying features. Motor theory furnishes thus the basis of unifying the functions classed as learning, perceiving, remembering and imagining. The so-called "higher processes" of problem solution and thinking are likewise instances of the same sort. When your car refuses to start when the starter button is pressed, the frustration of your getting to your office or to the party or to a show initiates the substitution of a different set of movements. You check ignition, carburation, etc., in order to first find and then remedy the "cause". "The problem-idea initiates and sustains prolonged action, the seeking to comprehend or the thinking through. Its characteristic is the 'persistence of its

influence'." The problem-idea starts a movement system into action, and one so complicated that the action is not worked out in a brief space of time. "The activity of such a system has a strong tendency to recur." (p. 154). This fact is important. My visual world is set up in terms of my egocentric reference. What I did yesterday and one or more years ago leaves what Koffka and others have called memory traces in the sensory-cerebro-motor mechanisms of my body which are individual to me. With the passing of time these become foreshortened. Details drop out. Stereotyping is characteristic. The sight of a road leading from a transcontinental train elicits the internal speech, "This is the road we took six years ago on a memorable holiday" and the gross and salient events are recalled. But there have been important changes. The distances now seem much smaller. The mountains less high. The apprehensive 'tenderfoot' attitude well remembered as of the first trip, is gone. The meaning tendency and determining tendency to react again to the same scene is now a part of a movement system which has passed on into a new phase of its existence.

Purdy has pointed out a fact, referred to by J. P. Nuel, Mussatti and much earlier by J. M. Baldwin and Sully, by Ach, Messer and Witter, that the motor transforms the sensory. There are many evidences of this. For example if we look again to the skin and examine the problem of localization, the classic doctrine of the local-sign of Lotze, like the similar doctrine of corresponding retinal points which Hering called "cover points", does not hold. Lotze claimed that every point on the body surface has beneath it a distinctive and different pattern of skin layers, blood vessels, fascia, and nerve endings and so each point yields on stimulation a distinctive and local index or sign of position. Opposed to such a very simple explanation we may cite two brilliant experiments. The first by Dr. Harry Helson in which he described what he calls the TAU effect. If a point, say on the volar surface of the forearm is stimulated and shortly after a second point not too distant from it is a little more strongly stimulated, the first point will be localized much nearer the region of the second point. Or if three equidistant points are stimulated in such succession that the time between one and two is twice that between two and three, the relative distances between the two pairs of points will be as about two to one. If Lotze were right, this could not be. Second, the late Professor Joseph Peterson also studied the problem of cutaneous localization with his characteristic care and thoroughness. His conclusion, likewise, was against the acceptance of the classical local sign doctrine of Lotze. Peterson proposed, as a result of his experiments that "local signs" are really orientation tendencies. That is another way of saying that when an irritation is set up on any region of the skin sufficiently strong to be noticed a movement is instigated to bring the hand or finger to that spot to brush it off or to remove the source of irritation. In the classical experiment of the drop of acid on a frogs foot, he attempts first to shake it off with that same foot. If the stimulus persists, he makes the crossed extension movement and with the opposite foot attempts to wipe it off. If this fails, the action spreads and moves up or down the cord until ever widening groups of muscles contract in the effort to free him from the source of irritation.

Damaging also to the classical theory are the experiments on skin transplants. The work of Dr. Lyle Lanier comes to mind in this connection. If a piece of skin from the thigh is transplanted by a plastic surgeon to make a new cheek or nose or chin, after the regeneration of the blood and nerve supply it becomes possible to study the two point threshold, the errors of localization, the pain, temperature and pressure thresholds of this region both in the original locus and in the new transplant position. When this was done the broader view of Peterson was sustained and again confirmatory evidence adduced in support of the motor theory. It seems quite clear that we must not continue to think of any 'sensory' process as purely local and unaffected by the fact that stimulation is basically an early stage, phase or episode in the chain of events which leads to a new kind of orienting adjustory movement.

Finally mention may be made modestly of my three papers several years ago in the Journal of Genetic Psychology on the comparison cutaneous localization in congenitally blind and in seeing children and adults. Here again Peterson's results were sustained and some interesting and important comparisons made: for example, seeing children were more accurate than seeing adults; blind children were significantly less accurate than blind folded seeing children; blind a-

dults were superior to seeing adults; blind adults were superior to blind children. These generalizations were qualified by pointing out that as age increased the size of the errors was largely determined by which of four methods of localizing studied gave the greatest accuracy and hence was made the basis of the age and sight comparisons. The fixity and rigidity of the local sign doctrine cannot be made to explain these findings.

Dodge has shown that we are living bundles of habits, many of which through long exercise have become telescoped, foreshortened and degraded in the hierarchy of the central nervous system to the status of determining tendencies or reaction tendencies. That is, sensory afferent processes always overlay and touch off the mechanisms already largely set and ready to go. The set and ready to go, Washburn has shown, gets direction and limits in terms of our perception of the total situation now and the tentative and provisional consequences of what will happen if we pursue one course of action rather than another.

Movements are the basic substrate of all mental life. Immobilize a man for a prolonged period and what happens to him? What happens to all of us in senescence? With Dr. Edwin Guthrie mental life is muscular life - if by 'muscular' we may mean all effector processes and all contributing and regulating biochemical motor functions.

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MOTOR THEORY: XI

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In an early paper of this series a neural schematic diagram was presented to illustrate the concept of the organic circuit. It was presented in order to show that the backstroke from proprioceptors completes and unifies the act and that the reflex as a small, local and more or less isolated portion of the total circuit is an artifact.

The moment we consider the development of half-centers and the multitudinous possibilities for relaying to higher and lower levels, as well as to homologous and contralateral conductors and effectors at the same segmental level, we see the mechanism for surrogation, for conditioning, for every sort of abstract signaling. Through the backstroke the muscles which move the arms and legs, and the muscles of speech become parts of the visual process. Seeing is never complete until the stage is reached in which there is some adjustory movement. This is why kinesthesis, to quote E. B. Titchener, is "the common denominator of all meanings." It is the residual after-effects of movements which constitutes the sets, attitudes and determining tendencies which, Dodge showed, are just as important determinants of subsequent sensory-motor functions as are the physical instigating stimuli themselves.

It is my studied opinion that we may even go a step farther. We may postulate that the changed patterns of energy distribution in the brain following prolonged stimulation are instances of one form of reactance in living protoplasm closely similar to or identical with the electrotonic effects or satiation effects described by Köhler in his studies of figural after effects.

In this paper I wish to propose a further amplification of the schematic diagram of and earlier paper, referred to in the first paragraph. Suppose we draw in additional conductors from the visual cortex in the occiput and extend them forward to the frontal lobes. Not much is known directly as to the function of the frontal lobes, but Halstead and others who have studied extensively many cases of brain injuries to this region, and patients following frontal lobotomies, are of the opinion that the frontal cortex is a synergizing mechanism. It unscrambles the beating frequencies and homogenizes them with the residual traces from prior experience. But no impulses of energy can vanish into nothingness here. Any shaping or forming of the efferent discharge (co-ordination and correlation) is but an earlier prodromal phase of some type of consummatory movement or act.

It is not at all unlikely that here the parietal motor regions come into activity. Again, <u>what</u> groups of muscles will contract and <u>in what order</u> temporally is almost certainly not settled in the occipital or in the frontal cortex. The work, previously cited, of Marina, Anrep, Beck and others shows this conclusively. Rather we must look to the increased rhythmic activity of specific effectors which synchronizes them with the pattern in the frontal cortex, again through the mechanism of the backstroke. We can think of the almost endless combinations of effector patterns as subsystems ready to join the whole chain set in activity by the the excitation of the distance receptor. Only those can receive the cortical reinforcement which are ready; that is only those whose phasic tonus has been heightened at the moment by the lowering of the postural tonus of the smooth muscle components. Evidence for this statement is not wanting. Spastics have walked following sectioning of the gray rami in the femoral region. The maintenance of posture (Magnus and de Kleijn, Sherrington, Adrian) can be accomplished because the phasic movement can be instigated only if the tonic or postural mechanism, mediated through the old nervous system, is inhibited.

Visually there is no object or form discrimination below the corpus striatum (Marquis). Nor is there any form vision when the afferent volleys reach the cuneus or occipital lobes. Nor is there any when the forward relayed volleys reach the frontal lobes. It is not until the effectors have been thrown into activity, and the backstroke from them forms the unit organic cir-

cuit that we may safely say that form vision occurs. We may do this because, if because of the action of drugs (curare, for example), or extremely lowered tonus (sleep) or from progressive and widespread relaxation the effectors cannot act, there is then no awareness of objects as objects, no naming, classifying.

There is another powerful example of the primary importance of the motor processes. This is formed in the studies on the acquisition of skill. Learning to make a simple skilled movement is clearly a process of transforming an early stage tension movement, in which there is opposition by antagonistic muscles in contraction throughout the course, into a smooth, fluent ballistic type of movement in which the limb swings freely and is unopposed and uninfluenced by any brake activity of antagonists. Stetson, who has done brilliant work on this problem, has shown that the transition is effected during practice or training largely in an ex post facto manner. It is virtually impossible to watch an expert golfer sink putts of varying lengths and duplicate his work merely by watching his movements. Any reorganization of an action system has to issue from the transforming of the acts themselves and this through the perceptual reorganization of the consequences of the act.

Finally, Lashley and his students have reared chimpanzees in complete darkness for 16 months. When thereafter they were tested in the light for the visual control of movements, the general findings confirmed the same conclusions from the studies on aphakias. The visual signals to become effective must be structured in the field whose primary components are movement produced.

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MOTOR THEORY: XII

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This final paper in the series on Motor Theory will attempt to summarize and review the evidence and the arguments presented thus far to show that all functions of the sense organs, as detectors of energy changes in the world, both within and without the body, must be regarded as belonging to, and as part of, the adjustory mechanisms. The evolution of distance receptors - olfaction, cutaneous temperature, hearing and vision - and the increase in the size and weight of the brain parallels the evolution of more and more complex forms of individual and social behavior. As vertebrate organisms developed finer speech and manipulatory movements, the gains brought on from the elaborated new forms of behavior accelerated. Our present culture represents the apex of organic achievement.

There is little question that daily living enterprises today impose greater demands upon our sensory - cerebromotor systems than in any period of the history of our long struggle to master the forces of nature and to live freely and well. Likewise there can be little questioning of the fact that a large fraction of the human race can be trained to hear and see, smell and taste much better than in the present untrained case. Nor can anyone doubt but that increasing the sense-perceptual range of the individual multiplies the number and kinds of adjustory movements - the behavior repertoire of that individual.

It is a principal function of motor theory to place due and proportionate emphasis upon the role of the effector organs and the backstroke, or returning afferent volleys from them in the mental life.

We have no means of knowing how widespread is the teaching nor how much damage has been done to progress by the erroneous doctrine of the eye as a camera and of seeing as a constant process of retinal copying of the kaleidoscopic physical patterns of light which reach the eye. If one will carefully study the process of the visual perception of any common object, of size, position, distance, brightness or hue, he will ultimately conclude, if he has any competency as a scholar, that the process cannot be completely described and understood, no matter how fine the measurement analysis of what happens within the eye. And no matter what construction we may place upon the events which occur in the brain cortex following visual stimulation we cannot disregard the fact, ably pointed out by Purdy and clearly demonstrated by others, that the executant mechanisms of the body - the muscles and the glands can and do transform the sensory.

In presenting the case for the just and rightful emphasis upon the role of movements in seeing, hearing, etc., we wish to make it crystal clear that in so doing we do not minimize or detract one particle from all or any of the fine work that has been done on the biophysics of light, on physical and geometric optics, on the histology of the structure of the eye. If my interpretation is correct, motor theory simply insists that we must take all of this and go a step farther - perhaps several steps. It argues from the evidence that whatever removes from the intact organism its capacity to execute the adjustory movement (drugs, hysteria, anesthetics, progressive relaxation) also removes its capacity proportionately for 'sensory' discrimination.

If the pattern or the intensity or any other property of the stimulation of the sense organ were the determinant of the ultimate reaction or adjustory movement, then Fulton was wrong when he wrote that "the central nervous system is organized, not in terms of anatomical segments, but in movement patterns." In our language perhaps our first and most important words are action words - verbs. Most of our nouns and possibly all of our meanings derive from them.

In our first paper we wrote that "The central nervous system is not only organized in terms of movement patterns but movement patterns are primary agents of organization of the sets of systems within systems which comprise the unified behaving organism able to sustain itself in its station or habitat

in life."

From surgical nerve transplants it was shown that "the pattern of effector action is not set or predetermined by the brain" and "it follows that the stimulus - impression upon the sense organ is similarly neither the determinant of the central conduction gradients, nor of the consummatory response series." From one point of view even the simplest case of the excitation of irritable protoplasm is a motor phenomenon, that is, it is an adsorption of ions at a surface with resulting alterations of surface tension, electrical polarization, semipermeability, that is to say a primitive species of reactance.

In paper No. 2 attention was called to our previous papers on fields and field organization. If there is disjunction, or lack of unity, in field organization, competing tensions may produce incompatible movements, blocking, blurring, loss of meaning. A main defect of the elementarism and atomism in the sensation doctrine, was of course the necessity to postulate some sort of force of conjugation to piece together into some sort of unity the random and successive fragments given by the so-called purely 'sensory' processes. This was met by the classical doctrine of association. Titchener showed that meanings are associated, and meaning derives from kinesthesis, i.e., from the backstrokes and memory traces of prior consummatory acts and their perceptual consequences. Von Ehrenfels was quoted to show that the essential quality which determines a pattern is its underlying meaning, just as Helson showed that for configurationists "motor reaction - patterns are determined in their temporal order by the end or goal which may be an integral part of a configuration even though it is not present in time and space. Part activities can thus fit into meaningful ordered wholes for which the ground or connection is the concept of the configuration."

In paper No. 3 the work of Minkowski, Coghill, Preyer, was cited on the ontogenesis of behavior. Up to a few weeks before birth there are no established conduction gradients or 'paths' in the central nervous system between the sense organs and the muscles. Movements are of the form of mass acts. Movements become specialized or individuated, biologically useful, significant or purposeful very slowly.

Habits or skills are thus not mere conjoined series of unit reflexes. Learning of manipulatory and perceptual skills takes on something of its true importance. The modern concept of the 'reflex' as an organic circuit was diagramed and the trigger like role of sensory stimulation emphasized. In 4 the role of the effector processes, both sensory and motor, in providing for unity and continuity in behavior was emphasized, and Parsons' analysis of the tropistic and directional character of early first movements was presented, particularly the notion that vision evolved as a specialization of the temperature mechanism. "The chief functions of vision, biologically considered, are the control of the individual's movements, and the perception of movements in objects in the outer world" (Parsons).

In 5 the function of the backstroke as the primary agent of integration was pointed out and the role of the chemical mediators, such as sympathin and the sympathomimetic substances indicated. Effector movements are therefore partly controlled by the chemical conductors or the excitatory and inhibitory substances produced in other parts of the body. It is recommended that this paper be read in its entirety. It is not possible to further condense the arguments of pp. 18-19. 6 dealt with the expanded concept of seeing, as an act, laid down in papers 1-5 and referred, in addition to the evidence of Cannon and Rosenblueth on chemical agency in the control of movements to the functions of the pace-setters (Crozier, Hoagland). "The backstroke is the mechanism which extends the visual process to include the effectors - in so doing it establishes the perceiver's empathic point of vantage and permits him to orient himself and his world of seen things." In 7 the pacemaker was discussed and the further role of movements pointed out, namely of the myogenic controlling influence originating in the effectors. Relation to the problem of adaptation and the nonvisual determinants of visual space were pointed out. And in 8 after brief discussion of the ambiguities of the meaning of the word space, Berkeley's view (1709) that "space as a psychological construction resulting from a coordination of the senses, particularly of sight and motion" was cited. Space is probably never purely sensory since its essence derives from movement (kinesthesis). Evidence was presented against the argument that visual training merely enables the perceiver "to

interpret a blur." Evidence was presented to show that form is as much an episode in function as the converse and that in seeing as in any skill the virtuous performance is occasioned by a new and different set of functions characteristic of any true learning. 9 continued and extended this argument, quoting from the experimental and theoretical works of Dodge, Titchener and Knight. 10 discussed the extension of motor theory to the so-called higher processes, intention, purpose, desire, etc., all of which have the common characteristic "to pass beyond themselves and become something different." The essential agent for this is some sort of act. Washburn's theory of movement traces as the basis of the recall of mental imagery and an essential item in thinking and problem solution was quoted. Finally, if you have read this far in 12, you are advised to read again 11 in which an attempt was made to theorize further regarding the true functions of the parietal and the frontal cortex.

It is the candid opinion of the writer that a thoughtful study of this group of short papers will give a fair introduction to motor theory. It is further believed that it will have important consequences upon practice.

In apologetic vein it should be clearly understood that so broad and important a subject cannot be treated with anything resembling the thoroughness it deserves. Too, there have been important omissions. For instance, several years ago I wrote a paper still in my desk on a motor theory of intensity because I believe that the true solution to the problem of how we discriminate intensive differences can only be found in the movement produced consequences of sensory stimulation.

In visual training we know that there is no substitute for short stroke sketching in assisting a person to see visual forms in true perspective relations. Speech and language began as gesture, posture, mimesis - and largely remains so even in ultimate stages. All life is synonymous with movement and action "I rest and I rust" was an old German proverb. In senescence it is the failure of the muscles which the Book of Revelations so aptly describes.

The prediction can safely be made that research in vision in the years to come will see more and more developments of the control of sensory processes through the more proper management of the kinetic systems. As I see it every phase of every visual examination which leads either to lens application or training or both is an assay of functional performance or of functional potentiality. The paradox is that those who should be vitally interested in this type of thinking almost to a man disregard or oppose it.

But for those who take this position it may be well to recall that one of the ablest theorists and investigators in experimental psychology wrote a quarter of a century ago that "the sensation doctrine is a dead issue. It represents a closed chapter in the history of experimental psychology." Unfortunately it is not a closed chapter in certain scientific and technological regions of vision. Just in so far as such is the case ashes are being raked and reraked.

In closing we move on to space, time and motion as the topics for the next series We shall try to make these forthcoming papers integral with volumes 5, 6 and 7.

Psychological Optics

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SPACE, TIME AND MOTION: I

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If twelve papers devoted to a consideration of Motor Theory could give but a brief and partial exposition of the role played by the mechanisms of movement, one must approach the above topics with even greater misgivings.

It is, however, quite natural and logical to deal with the above trilogy after having attempted to show something of the importance of the part played by movement produced excitations in our mental lives.

Space, and with it Time and Motion, are fundamental physical concepts. As such these concepts have occasioned extended discussions and experiments and theories from the earliest times. For those interested in the problem of how we see, we have not far to seek for ample justification for the consideration of space, time and movement likewise in the world of human experience.

Let us consider a few examples. As an infant grows and develops, it is generally agreed that one of the very most important things he 'learns' as he passes each stage en route to adulthood is that he learns to perceive space relations. The late Kurt Lewin several years ago showed a motion picture of his toddling daughter in her attempts to learn to sit down upon a stone a foot high and shaped like a small hassock. She would look at the stone from a point ten feet distant, walk forward three fourths of the way, turn her back to the stone, attempt a few back steps (but not enough!) and sit down. Her contact with the earth was solid and real. Her surprise, chagrin and anger and her amazement that the stone was not in spatial position which her visual estimate had given her could become the starting point of an extended treatise. I well recall that after two such unsuccessful attempts to learn to sit down at a particular place the child cautiously approached the cylindrical rock, patted her hands on its flat top as she walked around it. With a knowing look and still in tactual contact she was even more amazed when on returning to the starting point of her circular exploration she sat down - again not on the rock. One can well imagine the puzzling consternation of such a problem. One too can understand something of the space-time error of the high school boy whose car met the truck head-on in an unsuccessful attempt to pass the car ahead. Our every adjustory movement must be coordinated and oriented, must be right with respect to when, where, how much, in what order, etc.

Far earlier, in the evolution of visual functions, than the refinements of form or object vision, was the visual perception of movement. It is well known, for example, since G. H. Schneider pointed out, in 1878, that objects are more easily seen when they move a little than when they remain stationary. A shadow, he said, too faint to be perceived at rest could be seen when it moved. To quote Boring "the organism does not necessarily perceive a thing and then see it move, if it moves; it can perceive a faint or small object only if it moves. Biologically movement is prior to the other conditions of sensation."

Walking through a thick woods Helmholtz noted perspective was better if he was in motion. When he stopped the scene ahead flattened out. This fact has been proposed as a defect in painting. A picture can only give a view of a scene as it looks from some fixed point of vantage. The spectator must determine and not move from the spot where he is expected to stand, if he wishes to <u>see</u> the picture.

When our remote ancestors got along with the business of cephalization and with the getting of bigger heads (and perhaps better ones, too) they also got overlapping fields for the two frontal eyes, and when they also got partial decussation of their optic bundles they then had part, but not all of what it takes for binocular single stereoscopic seeing. Suppose we place before each eye a line drawing representing the left and right eye views of a truncated cone. Sup-

pose we look at the figures in a stereoscope. The figure, said Miss Washburn, will look flat because rivalry is absent, even though all the other conditions are met for the experience of depth and solidity. Since solidity is primarily a motor experience, involving the movements of grasping and handling an object, she reasoned that it should be redintegrated not by a static fusion of 'retinal images' but by an apparent movement. Based upon this hypothesis I wrote in my notes several years ago that depth is a form of motion - static motion, as it were. But static motion is a contradiction. Could it be that in a Cartesian three coordinate system representing space, where y is height, and x is breadth, that z is the axis upon which, if alternation to escape adaptation is within optimal limits of frequency, movement of the phi type becomes transposed from a single two dimensional object moving between two points in the x, y plane into a three dimensional or "real" object? It seems a plausible argument.

Rivalry or alternation is as much or more a cortical than it is a retinal fact. It was Washburn too who discovered that it occurs in our ordinary perceptions of solid objects. It is a natural conclusion that we must therefore regard stereopsis or depth perception not as the combination or 'fusion' of two slightly different images on corresponding points of the two retinas, a purely optical and ocular matter, but as something more fundamental and more extensive than that.

Ernst Mach showed, many years ago, that it is not necessary to have the two views delivered simultaneously to the two eyes. Perfect stereopsis can be achieved if the stimulation is alternate. Dr. Howard Snyder studied a phase of this problem in our laboratory. He arranged a rotating light chopper to interrupt the beams of two small projectors. Right and left views of white squares on a ring stand in a golf course were projected. The beams were polarized and the observers wore Polaroid Viewers. At slow speeds a perfect phi effect was seen. The target was single and moved from side to side through a distance determined by the decentration of the screen images.

At 20 to 34 cycles per second, the 12 observers reported, the lateral apparent movement stopped, and at alternation rates above this, the figure was seen singly and tridimensionally. Flicker was extinguished at 40 to 90 cycles per second, depending on the observer, and there was an absence of relation between the critical flicker frequency and the extinction threshold for the apparent movement.

It should be borne in mind that the phi effect in normal stereopsis is optimal at the phase rate of about one second for each eye. This rate is determined by clearly structured black targets on a white ground. If anaglyphs are used, the results will be different. This is true of rivalry, also.

If a single rapid exposure is given in which stereo figures are shown appropriately for third degree fusion, of how short duration may such exposure be and depth be seen? Early this year we made several experiments with a quartz-mercury lamp of high intensity of illumination at two to four microseconds (millionths of a second). Observers with normal stereopsis had no difficulty in seeing pictures, geometric designs, etc., in the third dimension at two and three microsecond exposures. Two graduate students were able to reproduce nine digit numbers at .000003 seconds exposures.

If depth can be seen at such exposure speeds, then it would appear that, since the latency of the photoreceptors is from 2-1/2 to 5 thousandths seconds, the stimulus and the sense organ are at the most only partial determinants of depth or solidity in seen objects. The function of stimulation is trigger like to set off or rearrange the distribution of energy within the field. The field is constituted of effector and cortical components as well as afferent impulses from the sense organs. The meaning of depth, or solidity, is derived from the redintegration of the motor after-effects of handling and manipulative movements, and the chief role of the impression is to instigate the process. Movement is an essential factor in the development of our individual space lattices.

It should be borne in mind that attention was called, in a previous paper, to the many different ways in which philosophers and scientists have defined space. It should also be clear that in physics it is customary to think in terms of a single system which is invariant. The centimeter, gram and second are the same always everywhere. There are, of course, other systems used in more advanced physics, in which such is not the case. But generally we use the single standard system for the measurement and description of objects.

In psychology, however, or better in our phenomenal or everyday experience there are many spaces. On the skin the two point threshold varies from locus to locus. The cupped hand on the back of the head gives the impression that the head is the size of an orange. Visual space and haptic space are at variance and the auditory space world is unlike either. Yet each of us has to resolve out of these differences sets of adequately spaced and timed adjustory movements.

Does anyone question the facts, shown by often repeated experiments, that experience and training can and do transform the space lattice? Stratton showed that if the visual position of an important door knob, switch, button, differed (because of the wearing of prisms or mirrors) from the tactual, kinaesthetic or manipulatory position, soon the things came to be seen at the operational position regardless of position in the visual field reported by the eyes.

Where we localize any object within the visual field is a matter of projection. By projection we mean simply the fact that while the sensory-cerebro-motor processes all take place within the body, we ascribe the position of the object to some locus out there in space. We see things where we must go in order to touch, feel or manipulate them. What would my vision do for me if I located the things I see inside my head? I may just as well, and perhaps better, be blind.

What is the mechanism of projection? Certainly the eyes do not extrude streams of formed light, like a projection lantern and in some mysterious way fit the "image" exactly upon the object out there? And it is equally certain that the horopter (the sum total of points in space which can be seen singly by the two eyes) is not determined by Hering's "cover points." If it were, why for example, would a change in brightness also change the apparent size and distance of an object? Or why does the alteration of the peripheral ground so radically change the central figure?

Two further facts must be placed in the picture as we look forward to a consideration of the modern views of space, time and motion. Rudolf Luneburg has examined the problem of binocular visual space from the point of view of mathematical logic. His monograph is destined to become a classic. It certainly marks a turning point in optics, because Luneburg shows that binocular space is non-Euclidean. After applying several geometries to known phenomenal facts of binocular space he finds that the geometry of Lobachevsky is the most satisfactory. Visual space is hyperbolic.

We have tried a preliminary application of his fundamental equation to our size-distance data on 139 cases with surprisingly accurate results. More extended study is now in progress. Luneburg's work means clearly one thing: there will have to be a large amount of redesigning of targets, apparatus, methods and concepts in every measurement which involves binocular vision. Talk, for example, about "the curved horopter of the myope" is meaningless. In fact the whole concept of the horopter must be fundamentally restated.

Second, Köhler's more recent work on figural after-effects in the third dimension is so important, both for visual diagnosis and training that this too is a classic. It is a safe prediction that nothing that has happened in recent years in vision will stimulate more research than these two splendid works.

My interest in these problems began with my first course in laboratory psychology many years ago. That interest has never been as eager and held so much promise as now.

Psychological Optics
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SPACE, TIME AND MOTION: II

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Space perception is so important, not only in and of itself, but its role in the evolution of behavior forms, both phylogenetically and ontogenetically, is of first order. Any living thing which suffers only a partial impairment of its ability to discriminate position, direction, orientation, point de repère (landmark), is to a proportional extent set to suffer marked restriction of its adjustory behavior or to meet even more drastic consequences. It has been long a biological puzzle how, for example, in my own back yard an ant, a bird, my dog and I can all get along with the business of living our various lives each in a space world so different from all the others. The bird with his ditch foveas and panoramic vision with a wide range of accommodation, and with essentially zero contributions from his skin and smell yet does all right in getting about in three dimensional space. The dog, color blind and, beyond a few feet form blind and with almost no accommodation, has his problems: They are certainly not the ones of the ant, the bird and me. Somehow we manage to live in good peaceful symbiosis, at least until the ant decides he wants to seek new worlds and invades the kitchen, there to meet death at the hands of an irate hausfrau. A wise animal knows his space place and stays in it, or first structures it if he can to his needs for survival and behavioral freedom.

The most elementary consideration of visual space in man has to begin with an inquiry into psychological functions far older and more primitive than form and object vision. The lowest and simplest animal forms are positively or negatively heliotropic. Euglena, the flagellate, has only a part of its body which is responsive to light, but this part responds positively and the animal moves along the gradient of the greater light intensity. When a maximum point is reached in this series the reaction reverses. When certain chemicals are introduced into the environs, the same reversal effect may be seen. Thus we see that the sheer psychophysics of intensity begins to play its significant role far down the line of evolution. Parenthetically it may be pointed out here in passing that not nearly enough attention has been paid to this factor, as will be shown later.

If we examine a somewhat higher form like the metazoa with several sense receptors the intensity of the stimulus varies with the position of the body with respect to the source of the energy radiating from the object, say a food particle. Here there is a very primitive orientation with respect to the pattern of intensities in contrast to the purely directional tropism of the flagellate mentioned above. The earliest types of space discrimination are therefore largely derived from intensity gradients in the distal stimuli and the extent to which the animal can take their proximal equivalents as the starting point of a useful and beneficial change in behavior.

Let us suppose for example that a protozoan is stimulated by light on the right side and the light source moves to the left. There will be an immediate change in the body's reactions from one side to the other, chemical and metabolic and no doubt contractile or mechanical. Movement out there is met by or accompanied by movement 'perceived' by the animal as a change in his own behavior, of course of the most primitive sort. Space perception from the very simplest beginnings is therefore dynamic rather than static. One of its first fundaments is movement and the perception of motion. This we must examine as one of our first tasks in the effort to come to a better understanding of how we see space and form.

While other sense organs may possess a distinct superiority in some respects to vision as the primary means of space perception, yet in the process of evolution it was absolutely essential that visual space become superior to all other modalities for perception. A blind fish, for instance, swimming

in the water receives pressure waves upon his lateral line organs. Because pressure in water (or air) extends in all directions, rounds corners and casts weak shadows if at all, the lateral line organs are at best poor devices to indicate direction. Light is superior to sound, smell or taste because natural objects have for it a much higher coefficient of reflection. Light bounces from most common objects better and truer than sound, smell or taste. Parsons has pointed out that if all environmental objects were equally effective mirrors, "orientation would be as difficult as in a room with a thousand mirrors."

Let us add a further thought. Vision evolved as the primary space discriminating mechanism for still another reason. Because it gives accurate indications of the relative intensities and positions of stimulus sources at a distance it makes possible the delayed reaction. The animal with a good distance receptor can ready himself to meet his enemy, to eat rather than be eaten. If the eye were laid down early in the embryogeny this fact would be a strong incubus to the development of a better system of nerve and chemical integration of the effector apparatus of the body This is precisely what takes place. Anatomists have shown, at the Brush Foundation, for instance, that the child's eye is fully developed at four and one half years. And this is well in advance of his development of adequate space, time and motion discriminations. A six year old boy is peculiarly blind to where he 'mislaid' a toy only a couple of minutes before. In the embryology of the human the eye is laid down as early as the third fetal month. Can it be therefore that the evolution of binocular overlapping visual fields and tridimensional vision has been nature's way of making vision the effective substitute for the more primitive contact space discriminating devices? That it has thus enhanced survival values? That it has paved the way for the evolution of signaling at a distance (language and speech)? For abstraction and generalization - the things which brought on cephalization, and civilization?

There can be no question of the importance of visual space perception in our mental lives. Count the number of things done in the complete eye examination which involve it, in one way or another. This, of course, must be so. We have eyes to see with, sagely remarked the grandmother of Little Red Riding Hood to the wolf. If we see rather than just look this implies a much greater elaboration of the process.

However great our appreciation of the marvelous mechanism of binocular seeing of space and form we must not forget that much of this business of seeing is made possible by other nonvisual processes. Here I should like to present the case for the skin - the haptic and cutaneous senses. If we stimulate the skin with two small rounded bakelite cones a half millimeter in diameter on the volar surface of the forearm and seek to determine the threshold for two points, we shall find that if we work daily the threshold (i.e. the 'acuity' or resolution) of the skin surface will gradually diminish. At first two points to be felt as two must be separated by 12 to 14 millimeters. After perhaps a dozen laboratory sessions the observer now has a two point limen of perhaps 2.5 millimeters. What has happened? There has been no change in the number and distribution of the touch sensitive spots. These vary anyway from day to day, and no matter how carefully you work only a small percent of the spots remain consistently in the same locus. Like the retina, the skin has only punctate sensitivity to pressure. There are large interstitial insensitive areas.

When the limen is reduced, the change must be somewhere other than in the receptor organs. The same set of facts are true for localization on the skin of a point stimulated. Both point to the fact that the passive touch organs are poor devices for reporting space. They are also poor form perceiving devices. Press into the skin small copper shapes of differing sizes - triangles, rectangles, stars, parallelograms, etc., - and ask the observer to draw what he has felt. Cutaneous form like visual form, if untrained, will be poor and weak and inaccurate. Space and form and not native gifts. They must be put on like all other habits.

With the active touch things are very different. Place the two middle fingers of the right hand on the forehead at or a little below the hairline. Keep the hand still and move your head from side to side at different rates of speed. Now reverse the procedure. Keep the head still and move the hand from side to side. Note how different the experience of passive and active touch. When you feel the head with the hand, the head is a different kind of object. J. M. Baldwin called attention, in 1895, to the

fact that the active touch was the primordium from which all the other and especially the distance senses were derived; and he also asserted that in the individual's development from infancy to adulthood, the active touch sense in developing an awareness of the sizes and space relations of the parts of the perceiver's own body "builds up the egocentric 'self' which is the point of reference of all other spatial percepts and concepts."

Baldwin saw this cardinally important fact many years before it was rediscovered by Wertheimer, Köhler, Koffka and the other advocates of Gestalt theory. In later papers of this series I shall attempt to show how importantly it operates in the space discriminations we make in everyday living. Among other things it is one of the important reasons why I cannot accept the doctrine that visual form, depth and distance are determined solely by the factors of correspondence and conjugation. Any space formula which limits itself to the sense organ (the lens and retina principally) can hardly be anything but wrong. The evidence to substantiate this view will be developed throughout this entire series of papers.

I believe we have amply demonstrated in our laboratory in the last dozen years that a quick and sure way to enhance the visual perception of forms, sizes, distances and general space relations is through kinaesthesis. When an assistant trained in drawing gave instruction to Navy men in short stroke sketching, perspective and simple freehand building up of shapes, the visual perception of forms was greatly improved. This was by no means a new or original idea. In 1905 William McDougall wrote in his Physiological Psychology (p. 94) that in examining the classical "illusion" of Schroeder's stair figure, which is seen in reversal either as a stair or as a cornice ... "if these higher level paths connecting the visual and the kinaesthetic areas were destroyed by disease, the visual impression would excite the same visual sensations, but the excitation process would remain confined to the visual area, the kinaesthetic images would not be revived, and the impression would have no meaning. Cases of this kind occur and are described as cases of psychic (form) blindness."

Again, earlier, about 1850, M. de Boisbaudran of the Paris school of design, described in a book published in 1879 entitled 'Education de la Memoire Pittoresque' a method which gave singular success in training his pupils to draw. They were made to "study the models thoroughly before they tried to draw them from memory." "One favorite expedient was to associate the sight memory with the muscular memory, by making his pupils follow at a distance the outlines of the figures with a pencil held in their hands." "After three or four months practice ... their visual memory became greatly strengthened ... they had no difficulty in summoning images at will, in holding them steady and in drawing them." Further he says "their copies were executed with marvelous fidelity." Here in America, in 1877, at Fort Garry a Colonel Moncrieff reported that during the winter young Indians came to his quarters and were much interested in any pictures or prints that were put before them. On one occasion he noted a young Indian carefully tracing the outline of a print with the point of his knife. On inquiry as to what he was doing the boy replied that he traced it so he would remember better how to carve it when he returned home. In other words visual forms are seen better if the visual traces are set in a matrix of the backstrokes from the appropriate executant movements. Meaning, von Ehrenfels said, is the attribute of the organized visual field which differentiates it from a mere mosaic. And meaning is always kinaesthesis.

It is easy to see why we lay great stress on cheiroscopic drawing and tachistoscopic training, both phases of the same process, in visual training work. No other known procedure or method will take their place if we wish to eradicate the anisotropy of a space lattice which distorts and malpositions things, words, etc., in space perception. Or if we wish to develop in a perfectly normal system a quick, accurate and ready facility. No sphere, cylinder or prism can do these things. There has to be something more. That something more has to be based upon a fairly extensive understanding of the psychological aspects of seeing. Space perception was evolved biologically for one essential function - the control of movement. This in animals reduces to the avoidance of obstacles, the pursuit of prey, and the escape from enemies. Since the visual sense organ is the best one for space discrimination, it is noteworthy that the possession of good vision is almost entirely confined to actively moving animals. If we know how fast an animal customarily travels

through space, we can predict what kind of eyes and what type of visual functions he must possess in order to stay alive in his habitat. Any animal must not alone be able to control his own movements but he must also be able to discriminate motion, to perceive visual movement about him. In sessile or sedentary animals vision deteriorates or even disappears.

If you and I walk along, we cover about 3 or 4 feet per second and we can see all the objects in our surrounds clearly, even those close by. If we sit in a car at 60 miles an hour, we travel 88 feet per second and only objects at some distance are clearly defined. If our visual reaction time is about a fifth of a second, we travel a little more than 17 feet before we begin to put the brakes on and many more feet before the car is brought to a stop. If another car is moving toward us at the same rate the case is still just that more serious.

"We cannot estimate the capacities (of visual organs) by any ideal standard, but must seek them in relation to the specific kinds of movements and velocities, and above all in relation to the peculiarities of the nervous systems of the given animals, the most important factor being the reaction time" (Putter).

The visual perception of motion will be the topic of our next paper.

Psychological Optics
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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: III

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In order to excite a receptor some change in the distribution of energy must take place. The magnitude of the change must be of such intensity to be above the threshold for the particular receptor. The mode or type must be within the range (wave length, frequency, etc.) of the receptor cells. The duration must be correct, for if prolonged beyond a certain point in time adaptation or extinction takes place. The energy must change at a rate greater than a certain minimum. A change in intensity, or for certain sense receptors, in position or form or size or color is enough to maintain the stream of periodic afferent volleys in the nerve conductors. Movement thus is one of the very fundamental considerations in stimulation as it is in space perception.

If we fly over the same terrain at 250 miles per hour, ride in a car at 50, walk or ride a bicycle the number and kind of experiences increases as the speed diminishes. Our impression of the size and make up of a portion of the country changes radically with our rates of passing over or through it. Increased ease of moving about and of communication, tending to reduce the space - time barriers has transformed our lives culturally, economically and politically.

The space - time construct which we set up for ourselves is largely an individual matter. We more or less assume without much thought that the small portion of the world in which we move about in daily living is the same for the others with whom we come in contact. Adults tacitly assume that things and processes are the same for children as for themselves. The man who is six feet four and weighs 200 assumes that the fellow who is five feet four and weighs 145 sees his world from the same eye level above the ground. If the two men were looking at the top of my desk from the door of this small room the angular shape would be quite different for the two pairs of eyes. It is unlikely that the size of the object would be the same. If each were required to pitch a silver dollar to the middle of the green blotter, the swinging arc of their arms would be different as would be the muscular set or pitch of the movements. It makes a material difference visually whether for two persons of identical height the lines of sight incline or decline above or below the plane parallel to the earth. The taller the person the more he must depress the lines of sight when he walks or manipulates tools, etc. Notice, for example, the myope as he walks along unaware that he is being watched. His lines of sight seldom leave a point of fixation a few feet ahead on the ground. Likewise watch the deaf man move about and almost always you will see that his movements differ from those whose tonus has not been lowered by the sensory deprivation.

It was pointed out previously that one of the main factors in the evolution of vision was the discrimination of moving objects and the control of our own adjustory movements. In many lower animals the maintenance of life depends upon the ability to see movements. This is a primary function of the peripheral retina. In the human, Riddock showed in 1917 that following injury or disease the return of movement discrimination occurs earlier than form or color and begins at the periphery and progresses centrally toward the foveae.

It has been shown by a number of investigators that if a small spot of light is moved at a uniform rate across the visual field, the apparent velocity is greater in the region of the macula and diminishes toward the periphery. If a stationary object is fixated the apparent rate of movement will be about twice as great as in the case where the eye pursues the moving object.

The mere excitation of moving a spot of light over the retinal elements is not the exclusive demand for the seeing of motion. This was early demonstrated by Exner, Helmholtz and others in the following experiment.

If the after-image of a spot of light is projected upon a screen and the eyes are moved to a new position, the after-image moves also. But if the extrinsic muscles are anesthetized and the eye is moved with the finger or forceps, the after-image remains stationary. Likewise any fixated object remains fixed as to position if the eyes sweep over it, whereas if the eyes remain stationary and the object is moved we can produce the same retinal pattern of excitation but only in the latter case is the object seen as moving. Cases have been recorded in which there were bilateral lesions in the occipital cortex and when a moving light was passed across the field of vision, the subjects reported that they saw not motion but a series of stationary lights. It is obvious that the brain as well as the kinesthetics in addition to retinal excitation all play a part in the visual discrimination of movement.

How fast anything seems to travel before our eyes depends also upon the intensity of illumination on the object and the amount of light entering the eye opening; also on the subtend angle and upon the amount of brightness and color contrast. These factors we demonstrate in the laboratory with a stroboscope. This is a drum containing a number of vertical slits. Strips of paper bearing drawings or pictures of objects facing toward the center of the drum are viewed through the slits as the drum is rotated. When such factors as were mentioned above are kept constant the visual perception of movement reduces largely but not solely to two things: the angular velocity of the moving targets and the portion of the retina which is stimulated. Motion also can be perceived when "nothing moves", that is apparent movement may be seen with both the eyes and targets stationary. We shall return to this fact later.

In the fovea the smallest amount of movement which can be seen is about two minutes of arc if some adjacent stationary fixation object is in the field. Without such object the threshold of movement is increased from ten to twenty times. Below these values one must look for some time at the moving object in order to distinguish motion. The minute hand on your watch for example moves about 2 minutes of arc in a third of a second or 1° in 10 seconds of time. It is a significant fact that the movement threshold in terms of minimal extent is lower than the threshold for the visual discrimination of two stationary points.

Again, Exner found that two lights had to be flashed with a time interval of 45 milliseconds in order to be able to tell that they were not simultaneous whereas he could detect motion in an object when the time of the exposure was as low as 14 milliseconds. The difference limen or least difference in speed between two objects in motion which can be discriminated is about the same as the absolute threshold, that is about 1 to 2 minutes of arc per second.

Granit found that the apparent velocity showed little correspondence with the actual velocities of the light spots moving across the retina and assumed that this perceived velocity was directly related to the individual perceiver's size constancy index. Dembitz later confirmed Granit's observations. This is understandable from Wertheimer's demonstration of the phi effect. If two lights, like the red signal lights at the railroad crossing flash on and off alternately each being on for about 1 second and the eyes are held stationary, a single light is seen moving back and forward between the two points. When we set up a pair of mailing tubes in the laboratory and arrange the lights so that no light from the right light can reach the left eye, the phenomenon is seen just the same, that is a single light is seen to move between the two real positions of the lights. There can be little question therefore that motion is a cortical effect derived from molecular shifts in the interstitial space between the two foci of excitation in the brain which are the molar equivalents of the moving of a single light in space. This is the doctrine of isomorphism, at least in one of its forms, and was the starting point of much of the development of Gestalt or configurational theory.

We can see now how Miss Washburn reasoned and later showed experimentally that 'retinal' rivalry is an essential condition for stereoscopic vision. If both eyes see continuously, we would have alternate periods of blindness due to adaptation unless we shift fixation every 20 to 30 seconds or less. Two incompatible patterns will alternate at a rate which again depends upon several factors, one of which is certainly the electrostatic field state of the cortical areas involved.

If there is binocular fixation upon a single figure, it often happens that the shift in seeing-phase of left to right eye can only give the slightly changed aspect of point of vantage due to the interocular distance.

Thus in the so-called illusions of reversible perspective or the change of figure-ground relations in a single figure we see how this principle must operate. Suppose however that total field factors are such that a change in position horizontally (x axis) or vertically (y axis) cannot take place, or that the resolution of the brain field forces gives the vector on the z axis. We then see the object as having tridimensionality probably due to the fact that among the strongest of the determining field forces are the traces of the kinesthetic impulses which have been set up through actual manipulation or body movement in the third dimension. Vision thus evolved the trigger like means of redintegrating the meanings of solidity, depth or z axis extension toward or recession from the frontal plane. Neither the brain or retina alone could do this. This theory which has the merit of being susceptible and feasible of experimental test is now being vigorously studied in our laboratory.

Phi movement is pure movement, seen in the absence of any moving object. The seeing of motion is thus older and more primitive than the seeing of form or position and the assay of this and related functions will become an essential measurement in those cases of visual difficulty not readily or satisfactorily handled by the standard type of eye examination. In fact it is not at all unlikely that the time will come when the <u>complete</u> eye examination will enable specification to be made which will find no longer useful the classification of types such as hyperopia, amblyopia, myopia, strabismus, etc. Consider for example the original meaning of the term myopia. One thing is certain that the concept of a static and homogeneous visual field is never true of any person whose vision is either normal or abnormal.

Kenkel in 1913 noted that under alternate presentation the central line of the Müller-Lyer illusion figure would lengthen and shorten. This change in the size of objects he called alpha-movement. It is simple to show the combination of phi and alpha. When we do this stroboscopically a box like drawing will roll over toward the observer in a continuous circuit. If the inspection period is long enough, a minute or two, this movement will cease and the figure will reverse position just as in the Necker cube. Both phi and alpha movements are two dimensional affairs. Thus we are able to demonstrate that the third dimension can be generated out of them.

Kenkel gave the name beta-movement to the change of position of an object. A black dot seen at clock positions 12 - 3 - 6 - 9 and 12 will be seen to revolve in a circle smoothly rather than to jump in a diamond from one post to the next. If we cause the circle to rotate in a vertical rectangle, its orbit becomes elliptical. If the rectangular frame is now placed horizontally, the orbit flattens elliptically to fit the frame. Thus the <u>form</u> of the movement pattern is not predetermined by the distal stimulus. Gamma-movement is the apparent expansion and contraction of an object with the change of illumination from bright to dark or the reverse. It is an iris like movement. Delta-movement is a form of reversed movement seen when two objects are observed in succession with the second made much brighter than the first. In this case the movement is seen from the second to the first rather than from the first to the second. This is the probable condition which produces the reversal of the direction of the lawn sprinkler or Ferris wheel "illusion", that is the apparent reversal of the direction of motion. All that is needed is the change in relative brightness.

These are the most frequently used types or classes of visual apparent movement phenomena. There are of course others like the bow effect or the Umweg or detour seen in the phi when an obstacle is placed in the path of the transit in the field. In spite of Higgenson's objection to the field theory interpretation of these phenomena it is the view of many that many more observable facts are accounted for by this view and that the role played by movement discrimination as foundational to all space perception cannot be questioned. It is also most likely that the conventional theory fails utterly to account for many of the types of apparent movement phenomena seen in the commonest stroboscopic experiments.

We must give serious thought to visual apparent movement before we begin our inquiry into binocular space. It is here that space and time may be seen in their true relations.

Psychological Optics

—BY—

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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: IV

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The history of human thinking regarding space is marked by a number of noteworthy developments during the last half of the previous century. Before going further with our study of the problems of visual space perception we must inquire briefly into some of these developments in order that we may have a true perspective of the problems.

The discovery of the Bell-Magendie law (1811-1822) was one of these large turning points. This law merely stated that the dorsal root nerves entering the cord were afferent and sensory and the ventral roots were efferent and motor. Nothing was known as to the nature of the electro-chemical properties of nerve conduction at this time. J. Müller, the physiologist, for example thought that the speed of propagation of excitations in nerve conductors was six times as fast as light, i.e., light travels some 186,300 miles per second! The actual speed is about 100 meters per second in warm blooded animals.

With Bell's finding it was of course natural and logical that the concept of sensation inherited from the early philosophers should be taken over by the physiologists, physicists and psychologists. Here was evidence that the afferent (sensory) conductors differed from those which extend forth to the muscles and glands.

Fechner (1860) and earlier Weber had attempted to formulate the fundamental psychophysical formula, the intrinsic relation between the intensity of the stimulating physical agent and the magnitude or intensity of the resulting phenomenal experience. Weber found that within a considerable range of intensities the coefficient $DI/I = k$. That is to say if the physical stimulus applied to the sense organ was increased, progressively, equal increments of "sensation" or the perceived experience were produced by relatively equal stimulus increments. In lifting weights if, for example, a standard weight of 100 grams was compared with a series of 101, 102, 103 etc., grams and the smallest increment which could be perceived as just noticeably heavier was found to be 105 grams in more than half of the cases, then the relative difference limen or threshold was .05. If Weber's law were true, we could then predict that if we were to lift a new standard weight of 500 grams the same just perceptibly heavier weight would be 500 x .05 or 525 grams. In other words the more you have of anything, within certain limits, the more you have to add to make an appreciable difference.

The early work on psychophysics was an attempt to measure the strength or intensity of sensation, the elementary mental process, by measuring the amounts of increase in the physical stimulus which would produce equal increments of sensation.

Fechner attempted to generalize the relation by integrating and he came out with the equation

$$S = k \log R$$

in which S represents the sensation intensity, k is the Weber constant (DI/I) the R is the German symbol for reiz or stimulus. The sensation will vary with a constant times the logarithm of the stimulus.

To many it seemed that this early work gave great promise for a solution to the troublesome problem of the relation of the mental to the physical. Fechner of course clearly realized the intrinsic deficiency in the psychophysical formulation because he saw almost from the first that implied in his theory was the assumption that the summation of small part processes could produce wholes or greater intensive magnitudes. This shortcoming was clearly stated by William James when he pointed out that you never can produce a saturated red by no matter how many pinks you add together. Everyone who has done any metric work on the problem of intensity realized that qualitative differences are bound to appear when full description is made of an intensive series. For example, if in our taste laboratory we make

up a series of sucrose solutions in pure distilled water, that solution which is four times the threshold intensity is not simply related to one of twice the threshold intensity by the factor of two. There is a radical difference in the two taste spectra. The same thing holds if one attempts to compare two identical solutions one at 5° Centigrade and another at 37°.

It took many years of hard work in the efforts to measure sensations and to create a scale of intensive magnitudes before scholars began to raise the question: Are there such things as sensations? Is the concept of sensation a useful one?

Helmholtz, Wundt, Külpe and Titchener gave much thought to problems of this type. The early type of structural psychology was formulated after the pattern of the other divisions of science: You needed to have elements or elementary functions into which complex processes could be analyzed. The simplest and most elementary mental process was the pure, meaningless sensation. It was the simplest mental element. It was defined as an elementary process possessed of the attributes, said Helmholtz and Wundt, of quality and intensity. Külpe saw that this was not enough. He added extensity or spatial extent. Titchener added duration and clearness, and for certain sense modalities, vision for example, colors had in addition the special attributes of hue, saturation and brightness.

As the effort to specify the attributes went on there was much disagreement among those interested in the problem. Hering, for example, was faced with the task of accounting for the fact that some sensory experiences were clearly extended in space. Some were big and voluminous, while others were small, sharp and still others, smells for example, could hardly be said to have spatial properties at all. Hering solved the problem to his own satisfaction by postulating that spatial extent was a given. All people were born with attributive extensity. This position, called nativism, was like the doctrine proposed by Lotze and others, that every point of the skin surface has a local sign or sign of position which is a native gift. When a mosquito stings you on the left cheek you do not hunt for the place to scratch and you do not scratch your right elbow. Each position on the skin has its own distinctive local signature which is specific to that and to that spot alone. Together with Müller's doctrine of the specific energies of the efferent nerves the problem of haptic or cutaneous space had no need to arise.

But as is usually the case there were those who held the dissenting opinion even from the very first. As soon as experiments were made on the problem of space and its course from early infancy to adulthood, and as soon as factual information began to accumulate regarding the nature of nerve conduction and the true functions of the brain, the controversy between nativism and empiricism began to take on a different turn. Darwin, Huxley, Spencer and Gregor Mendel had imbued biological thinking with strong hereditarianism. Behavior in all forms of animal life was the unfolding and expansification of countless instincts. Schools and colleges were too late. You either were lucky in selecting the right parents who could give you the right genetic set of predetermining chromosomes or else you simply were charged off as a part of the appalling wastage of Nature. Professor Parker of Harvard University in a recent book for example, asserts that after many years of study he is convinced that 90 percent of our behavior, traits and capacities are due to nature or inheritance and 10 percent to nurture or training. It is obvious that this is an extreme position and will not be agreed to by large numbers of equally competent men.

Inherent in views of this type is the notion that the control of behavior resides almost wholly in the pattern of stimulating energy which reaches the sense organs. You and I are really nothing but helpless, passive machines. To predict and control our behavior you have simply to control the stimulus impressions.

It is hardly necessary to do more than point out in passing that the sensation doctrine soon became a problem not of sensations but of the attributes. As these were studied it became clear, as von Fey had so ably pointed out and as Berkeley had argued long before, that <u>vision alone</u> was incapable of furnishing us any accurate and useful information as to the size of objects, as to their distance from us, as to their true direction and rate of movement, etc. The case for sensation or nativism was not helped a bit by the discovery of the fact that all afferent nervous impulses are the <u>same kind</u> of intermittent waves of virtually transferred electrochemical energy no

matter from what sense organ they come. No known instrument of precision can possibly tell whether the afferent volleys reaching the brain cortex originated in the retina following a flash of lightning, from the ear from the clap of thunder or from the skin, muscles and tendons in setting ourselves in the posture of looking or listening. The brilliant British neurophysiologist, E. D. Adrian, in his 1946 Waynflete lectures at Oxford said that since "all nerve impulses are alike and all messages are made up of them, then it is at least probable that all the different qualities of sensation which we experience must be evoked by a simple type of material change." And, to quote further from the same lecture, "the activity of the brain from moment to moment should be capable of definition as a spatial arrangement, and no more." Sensory quality cannot be found in the specific region of the brain to which the afferent volleys are delivered because when these currents are amplified and photographed, there is no difference. Clinically also it is well known that if volleys arising from the retinas reach the occiput and are relayed forward to the frontal brain and throughout remain visual and only visual in origin, no object vision is possible. The perceptual meaning of objective form demands the supplementation of the proprioceptive, kinesthetic backstroke. If it is absent there is psychic blindness. Meanings are not intrinsic to sensory impulses at any special place in the central nervous system but originate out of the adjustory and consummatory movements of the organism and from the perceptual appraisal of the consequences of the acts of adjustment. The stimulus is a trigger like releaser of energy set to go (Verworn). It is just as true to say that in much if not all of our adult behavior we respond just as much to our own responses and to the residual traces of prior acts as we do to the instigating stimulus. How else can I interpret my finding that most observers can see perfect depth and tridimensionality in vectographs exhibited to the eyes for three millionths of a second? Particularly is this true in view of the fact that the latency of the photoreceptors is said to be somewhere between two and a half and five thousandths of a second. The quick flash upsets an equilibrium state. None will question the immense complication and the only partial understanding of the whole train of events which then follow to the restoration of the new equilibrium.

There are many evidences pointing to the theory that just as the sensation doctrine in the past quarter century has been practically abandoned, our perceptions of space and space relations cannot be satisfactorily explained by the summary classification of these functions as Nature's gifts. The form, size, position and distance of any visual object is a complexly organized arrangement of forces with the retino-cortical-motor field. It can be shown that if we measure by a matching method the apparent size of a standard target at various distances from the observer, such measures will show correlations approximating zero with visual acuity at far and near; with 'the subjective' or amount of lens power which must be added to give standard resolution; with any conventional measures of lateral and vertical phoria; with the stereometric threshold; with rivalry rate; with break and recovery points; with monocular projections. It is, in fact, almost certain that notwithstanding the cardinal importance of visual space and form perception in our lives none of the standard measures in the professional visual examination taken singly or in any form of combination give us the information we should like to have about this all important set of functions. Clearly there is here a very necessary field for future research.

If we begin our examination of space so as to become maximally clear and simple about the problem we must realize first that no one has a sensation except under the most artificial circumstances. Even before the eyes are stimulated there is an elaborate series of prodromal events to bring them to the posture of fixation, the focus, the constriction or dilation of the iris, the altering of the posture of the head and trunk, etc. Some form of instruction, self-imposed or other, sets us to look for shape, rather than size, brightness rather than color, position rather than distance, etc.

Thus Quality, Intensity, Extensity, Duration, Clearness become not the generalized attributes of hypothetical 'sensations' but each a specific perceptual or discriminative problem in itself. Such attributes are not independencies. The clearness of a figure depends in part on intensity and intensity in turn upon duration, and all these in turn upon extensity.

Again and again it has been clearly shown that how <u>extensive</u> a patch of light is seen

to be will be a function, not of the size of the retinal patches excited, but will depend upon its brightness, sharpness of contour, size and brightness of surrounds, hue, distance, duration of the exposure, the influence of what has been seen just before, and so on.

Space is interlinked with time and often inseparable. Helson showed in his tau effect that if 3 spots are stimulated on the skin equally distant from each other on the volar forearm, the interval between 1 and 2 being 2 seconds and between 2 and 3 one second, the observer reports the third dot much closer to 2 than 2 is to 1. If the local sign doctrine were true this should not be. Peterson showed that the localization of the spatial position of a spot on the skin was an 'orientation tendency.' From the random movements in infancy the outer surface of hands and arms are stimulated more frequently than the inner surfaces. Contact and extension become parts of a series of associated movements and localization eventually an approximating and correcting series of learning trials to remove or deal in some effective way with the stimulating object. We must realize from the studies of the newborn and the changes in behavior with growth, development and differentiation that the ultimate visual space is founded upon a much older and more fundamental set of space frames of reference. These are the skin, the cochlear and vestibular and the muscle, tendon and joint mechanisms.

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: V

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In the second paper of this series I called attention to the fact, first announced by James Mark Baldwin about 1895, that in the process of growth, development and differentiation from infancy to adulthood the active touch which comes with the manipulation of objects is of the utmost importance. If you rub your hand laterally across your chin and note the 'feel' of the apparent size of this part of your body and then look at your face in a mirror you will be struck by the obvious discrepancy between the reports given by eye and skin. Baldwin emphasized the fact that in developing an awareness of the sizes and space relations of his own body and the objects which come within the scope of its behavioral environment the perceiver builds up the egocentric self which is the point of reference of all other spatial percepts and concepts.

This fact is of great importance in the critical examination of the problems of visual space. In whatever way each of us builds his own individualized point of vantage the fact remains that the relative sizes, positions, movements, etc., of objects in the phenomenal environment are never and can never be wholly determined by the passive pattern of impression upon the retinas. Clear proof of this fact is not far to seek. Take your tachistoscope. Seat a dozen subjects before a screen and show them at a fifth or a tenth of a second a half dozen pictures of landscapes, people doing various things, buildings, etc. Ask each to give a full report of what he saw into a dictating or recording machine. Transcribe these and compare the reports. You will be surprised. Now read to someone else a few of these descriptive, enumerative or interpretative accounts of what was seen and ask your observer to pick out of the series of pictures all printed on one big mount the ones which each description fits. You will have another surprise. Neither of these effects are unexpected. This is simply because the process of the formation or structuring of a figure on a ground is bound to vary with the referential frames we each build for ourselves, with the things we have been doing, saying, hoping, fearing just before the view was exposed to us, with the totality of our sentiments, temperamental biases, etc.

This sort of fact of course runs counter to the still persistent trend noted in the work, writing and thinking of some psychologists and physiologists who are still 'tilting at the windmill', like Sancho Panza, in the effort to place the entire burden of the determination of what we see and how it is seen upon the retinal mosaic derived from the distal stimulus.

They do this even in the face of the fact that there is no correlation between the size of the patch on the retinas that are excited to high activation and the experienced size of the object. There is no rigorous stipulation even as to the relative position on the two retinas which receive the impact of light. Further the facts of contrast and bright relations prove that there is no direct physical relation between the number of quanta of energy applied to the receiving surface and the consequent discrimination of photic intensity. Anyone who has seen or witnessed the beautiful demonstrations of Dr. Ralph Evans of the color research department of the Eastman Kodak Company must surely have reached this conclusion. But no, even in the face of the fact that space perceptions cannot be predicted from any of the classical 'refractive' tests of vision or from any combination of them the implicit assumption carries on that that what happens at and in the sense organ determines the whole subsequent course of experiential events. That this is not the case is one of the major contributions of experimental psychology to visual science in the past half century. The human organism is a balanced system of systems within which the trend is toward homeostasis, unity, coherence. Whatever divides or separates function or systems of functions

leads to disorientation and to the ultimate breakdown of the essential biological and psychological adequate adjustment series in behavior.

If we pursue this motion a little we encounter inescapably the fact of the plurality of experienced spaces. Consider for example the facts known about auditory space localization, so important to the blind as well as to all those of us blessed with good vision. Seat a subject on a chair and blindfold him. Introduce a click from a snapper or telegraph sounder below the seat, directly overhead, to the right, to the left, in many positions in tridimensional aural space and ask him to localize the source of the sound. Explore his skin as to the two point thresholds and errors of localization from region to region. Make many measurements of his monocular and binocular space discriminations. Each sense modality yields its own particular meanings of the many spaces which contribute to the eventual single and total perception of the world as immediately experienced and of the locus of the observer in relation to it.

The basic problem which we must face is simply this: If there are many spaces and if these combine in some manner to produce a single meaning, how are these differing sense impressions integrated? What is the mechanism of integration? Certainly the geometry of tridimensional auditory space, bidimensional haptic or cutaneous space, monocular and binocular active and passive visual spaces is not the same for each of these.

If we can find a satisfactory principle of integration we shall have moved a long way toward the clear understanding of this fundamental problem of how we see.

I should like to propose that the agent and mechanism of space integration is the backstroke. The backstroke as has been shown in a previous volume of these papers is the pattern of afferent volleys arising in the skin, muscles, tendons, and joint surfaces activated in the process of making some sort of adjustory movement in the effort to restore a satisfactory equilibrium state after the stimulating situation has made the previous series of postures, movements or attitudes no longer tenable.

In previous papers I have tried to show that if the backstroke, which completes the organic circuit, is forestalled by injury, disease or drug action, there is an immediate radical transformation of the whole sensory-cerebro-motor system. Purely visual symbols although sharply impressed upon the retinas and transmitted through the radiations to the cunei of the occiput are meaningless, as Gelb and Goldstein, Rivers and Head, McDougall and others have shown.

Moreover, recent work on the functions of the frontal cortex, particularly that of Halstead, has shown that as the excitation patterns move forward from the occipital 'visual' areas the frontal cortex acts as a very definite region of transformation. Here the heterodyning circuits are "unscrambled", fitted into the form set by the traces or hysteresis effects from prior experience. Like the strikingly similar energy effects in modern electronic circuits the backstroke acts like the regenerative feed-back input in such circuits. In television, radar and in some types of radio communication that pattern of energy distribution and transformation bears a remarkable similarity to the kind of end result seen in perception. This is brought out strikingly in Halstead's very excellent studies of the functions of persons suffering from injuries to the frontal cortex, from brain tumors in this region and from the functions of persons whose frontal lobes have been removed surgically.

There are many analogies between the operation of relatively simple electrical circuits as well as the far more complex distributions of currents in field dynamics with the common observations of space and form perception. Functional interrelations can be understood in the development of motor half-centers, and Wedensky inhibition or blocking is strikingly like the simple sell known overcrowding or overloading of a conducting circuit. We can thus understand how the same nerve can act at one instant as inhibitory and at the next as excitatory and also how a nerve can transmit excitation to one muscle and inhibition to another at the same time. Professor Holt has called attention to the fact that "the only reason for any inhibition, its sole significance, lies in the fact that the contraction of a muscle opposes or negatives the contraction of its antagonist." Thus what muscles contract, and in what temporal and spatial sequence, is as much or more a matter of the set, posture or readiness of the particular

muscle to shorten or extend as it is of the receiving of a burst of ions from the terminal arborization of the motor nerve.

There is what we may regard as a critical frequency for flexion and if the efferent impulses are in heterodyning synchronism or if the intensity (amplitude, wave length or frequency) is wrong we can see a definite and clear means for the phenomenon known as Wedensky inhibition. Thus it is clear that the pattern of excitation from the sense organ serves merely as a trigger which starts in motion the chain reaction in the neuromuscular systems which will take whatever course the postures and sets of local regions will permit at the time.

This leads to a second necessary set of facts which must be kept clearly before us in our attack upon the problem of the visual third dimension and of form. Human behavior represents a continuum in space and time. Acts do not follow one another set end to end in time like the bricks in a walk. A large and essential part of the determination of the kind and amount of any movement is already laid down well in advance of the appearance of that portion of the total energy distribution in the universe whose change is sufficiently rapid and sufficiently intense to be classified as "the stimulus". Also, long after any observable overt movements have been made there persist active residual traces capable of exerting very strong influences upon subsequent stimulation and reactance.

We now come to a most important fact, developed from many experiments on the process of perception. This is the fact that the traces left from previous perceptions and adjustory movements undergo a continuous process of organization as they run their course in time. They tend to become simplified, conventionalized, stereotyped. Or, they may tend toward elaboration, expansion and amalgamation with other similar or opposing concepts.

This is shown clearly in studies on the method of serial reproduction. If I show you today a simple figure, a drawing of a vessel, say a teapot. But this teapot I show you has its own individual style, form or decoration. I ask you to examine it with great care so that you will remember it accurately.

After a two minute inspection period I ask you to draw what you saw, being careful not to name the figure in the earshot of the observer. An hour later I ask for a second drawing. A day, a week, three weeks, three months, etc., later I call for additional drawings. (The same procedure can also be done by letting you read or hear a descriptive passage or a logical sequence of arguments). If now I study the series of reproductions it is easy to trace the course of the changes as the drawings serially reveal them. Almost no one retains and recalls what he perceived in the original impression. If an error of shape, size, relative position of parts, etc., is found in the first drawing, subsequent ones will show the cumulative influence of the reproductions as even greater than the influence of the original perceptual impression. There is no question that details slough off, abstracted type forms are kept and run a course largely determined by the personally organized abstract masses of traces which are seen more and more as the integrating traces from the meaning-giving movements which are the eventual consummations of the whole process. Knight showed in his studies in our laboratory that individuals highly trained in the visual perception of forms come less and less to utilize visual and more and more to employ purely motor imagery as training is extended to higher levels of skill.

F. C. Bartlett has used the term schema to designate the "active organization of past reactions, or of past experiences, which must always be supposed to be operating in any well-adapted organic response. That is wherever there is any order or regularity of behavior, a particular response is possible only because it is related to other similar responses which have been serially organized, yet which operate, not simply as individual members coming one after another, but as a unitary mass."

The schema is not a persisting and fragmentary 'form of arrangement', he says, but "the organized mass results of past changes of position and posture are actively doing something all the time."

Let us now add to our theory the further postulation that the mechanism of schematization is the "feed back input" from the proprioceptive backstroke and that the locus of the transforming processes is probably to be found in the parietal interlinkage of the visual occipital and the frontal cortices.

In any case even though we do not at present know the precise functions of the new brain in the perception of space and form we may nevertheless set up the working hypothesis sketched above. It has the manifest advantage that many parts of it have been tested and have been found to be sound and workable. It has the added advantage that it points the way to the study of the problems of visual space in alignment with the biological principle that vision evolved primarily as the most effective means of guiding and controlling movements. To hit a buffalo with an arrow primitive man had to unify his estimation of the azimuth angle, trjectory, etc., with bow tension, timing of the release, or else he starved. Eye, brain, hands, arms, legs, etc., had to become a single unified mechanism. He had to learn to see things out there, not in the brain cortex. He had to learn, as did Stratton in his famous experiments, that we finally come to see things in space in terms of what we can and must do about them or in terms of what they may do to us. The fact that the so-called retinal image in "upside down" and "backwards" is of no practical importance whatever. So it is with Hering's cover-points. Any theory of visual space perception which insists that the simultaneous excitation of corresponding retinal points with decentered images is the sole determinant of depth and distance is certainly at wide variance with the known facts. It is far too limited in scope. It disregards the operationally most important features of the whole process of perceiving. To perceive is an active, transitive process. To perceive we must perceive something. It has to have form. It has to have position. It has to have size or spatial extent. These are not "given in inheritance" or native gifts. They are acquired skills. Their susceptibility to practice effects and training is one of their most obvious characteristics.

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: VI

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The problem of how we see objects in the third dimension goes back about four hundred years. That is to say the earliest serious attempts to formulate the basic principles of our perception of depth and form began about the time of Leonardo da Vinci (1519). It was not until 1575 that Maurolycus proposed that the lens was truly a lens and had image forming power.

Kepler (1604) the astronomer, extended the view of the eye and its similarity to the camera obscura and a century later (1709) Berkeley wrote his famous "Essay toward a New Theory of Vision."

Vieth (1818) and Müller (1826) and Wollaston (1824) were largely instrumental in laying down the foundations of the concepts of the horopter and of corresponding retinal points. Wollaston first pointed out the fact of the semidecussation of the optic bundles. In the 1840 to 1860 period the works of Donders, Listing, Hering and Helmholtz brought the problem of binocular space to the position not too much different from that found in geometric and physiological optics today. That is, the theory that space and form are derived from simple principles of correspondence of retinal points and disparity in 'retinal images' and that the solution of the fundamental problems of space and form is to be sought in the Euclidean geometry of the two retinal mosaics.

There was really very little difference between the Hering type of finalistic nativism which asserted that we just have space and form as native gifts and there is no need to fuss or inquire further about it and the quite simple set of somewhat more modern but equally too simple theories which held and hold that space and form are mere resultants of the simultaneous excitation of 'corresponding' retinal points with disparate 'images'. It shall be the purpose of this and following papers to examine the evidence and the arguments in the problem of the true role of correspondence and disparation in the perception of the visual third dimension and to sketch the main contentions of the most recent theories of space and form.

The invention of the stereoscope is credited to Wheatstone in 1833. During the next quarter century there was an unusually active period of testing the rational and geometric proposals which had been developed to account for space, form, size, position and movement. It is interesting that C. Scheiner had made his famous experiment almost exactly 200 years earlier and so the facts of crossed and uncrossed disparity must have been available long before the first refracting stereoscope. Convergence was known and described in 1613 by F. Aguilonius, who first defined the horopter. It was not until 1841 that the term accommodation appeared, its first application ascribed to C. Burow. In December of 1866 Helmholtz published the first edition of his monumental treatise begun ten years earlier, on Physiological Optics.

The classical theory of binocular singleness and depth is frequently stated as Tscherning's 'rule' that "when the images of an object on the two retinas are projected to the same side of the point of fixation they are seen single, their retinal images in this case falling on the retina to the same side of the lines of sight; when however the retinal images fall on opposite sides of the lines of sight and are projected to opposite sides of the point of fixation, they are seen double." The doubling of objects which do not fall on corresponding points was called physiological diplopia. This was but another way of saying that any point of convergence in front or behind the plane of fixation will be seen double.

The third visual dimension arose out of two differing two dimensional stimulus patterns presented simultaneously to the two retinas, or, as Mach showed, in not too long succession in time. If the regions of excitation

were superposed in the brain, being decentered, they were not homologous. According to the theory the brain could do one of several things: it could see double, or it could suppress one or the other of the 'images', or it could do what the common man knows it does under all normal circumstances, that is see an object as tridimensional and 'real'. How was this done? Curiously enough, the answer which sufficed many people for a long time was that the brain, torn in the dilemma between seeing singly or doubly, "effected a compromise" and the result of this compromise was the generation of the new (third) visual dimension. Such an "explanation" or the even more preposterous one that there is a "fusion center" in the occipital cortex the unique function of which is to imbue the two differing afferent volley patterns with depth and solidity, was held, and is still being taught, by men rigorous in most other matters pertaining to the logic of science. The whole problem of space, form, depth, distance was one of accommodation and convergence; of correspondence and disparation; of the functioning of what are called the secondary cues to depth - light and shadow, superposition, haze, color, etc. Note that in all the theorizing up to about the opening of the present century the effort to 'explain' space and form started with the distant object and the distal stimulus from it. The retinas, for the most part, for a long time bore the whole burden. You only needed to study disparity in the two stimulus patterns and the simultaneous excitation of corresponding points. But for at least fifty years there has been the troublesome fact, gained from scores of unquestioned experiments, that the number of instances in which such a theory does not and will not hold are far too numerous. Doubt as to validity grows rather than diminishes as you try to defend the theory. Just what shall we do about Panum's areas, the paradigms of Weber's circles on the skin and the doctrine of corresponding points? Why does correspondence seem to operate one way in the vertical and a very different way in the horizontal retinas? What, after all, is accommodation and what is its mechanism? What does it do in depth perception? What does the term convergence really mean? Questions like these are not easily answered. Last week I looked in the most recent edition (the 18th I believe) of a famous treatise on physiology to see how this modern book "explains" binocular space. What I read was shocking, dogmatic, antiquated. The whole problem was simply and quickly settled. The same story of retinal correspondence and disparity as the sole determinants of space and form could just as well have been written fully two centuries ago! Modern students of physiological optics are taught the doctrine as the only acceptable theory. In some quarters it is even presented as established fact!

No one questions the <u>fact</u> that decentration and disparity are important phases of <u>proximal</u> stimulation in the visual perception of the third dimension. Everyone should question the stated or implied assumption that these things, together with the cues from accommodation and convergence, are the determinants of visual space, form, size, position. No one questions the fact of retinal disparity. The issue turns upon the question as to what disparity does and how it does it. If, for example, a single point in the physical environment is projected upon two noncorresponding retinal points, it will appear double except when the amount of disparity is small. In this case it will be seen as one, but will be localized either in front of or to the rear of the plane of the fixation point according to the direction of the disparity. If the amount of disparity is varied as well as its direction, the <u>effect</u> ascribed to disparity is found not to be constant. Most of us will show quite a different range within which third degree fusion can be maintained if we go in the base-in as compared to the base-out direction. Further the distance and apparent size of any object can be changed radically while the disparity of the right and left 'images' of the object is held constant! This we have shown we can do by simply altering the relations of the grounds to the figure object. If we say that disparity is a distance cue utilized by the perceiver such a statement of the true role of disparity must be taken as unsatisfactory for the simple reason that we can not trust it. The correlations between carefully measured size and distances and retinal disparity are low, approximating zero. Professor E. R. Jaensch published an experiment in 1911 which likewise showed that disparity does not produce depth. In it he used a procedure which David Katz called <u>reduction</u>, that is bringing about of the state in which disparity operates uninfluenced by the presence of other interacting and intervening factors. Jaensch set up three threads suspended at right angles to the line of sight and with the middle one in front of the other two. His observers reported that the threads were

seen as a single figure like a wedge. The threads were left in the same position, covered with luminous paint and the room made completely dark. The threads were now seen as equally distant and in the same plane and there were definitely three of them. Jaensch concluded that the surrounding field must produce the stresses or forces which produce fusion and tridimensionality, not disparation.

Lewin in 1925 published a paper in which he went even further. Based on a series of experiments he concluded that "identity and disparity themselves are determined by the factors of organization."

Motion is an important factor as was pointed out in a previous paper. The marked superiority of a projection system seen in stereo such as the Sonne method over the best of 'still' stereo projection leaves no doubt that there are powerful determinants of the third dimension beyond disparation and correspondence.

In addition to motion there is the fact that contour sharpness is an important factor. One of the Titchener stereograms illustrates the phenomenon of luster. A white rectangle on a white ground on the left and a black rectangle on a white ground on the right are viewed in a stereoscope. Luster is seen. But if now we remove the thin black line enclosing the left hand figure no luster is seen and alternation takes place. Here the same conditions prevail in both cases except when the enclosing boundary of the left figure is erased it ceases to be a figure. A figure will interact with another figure and a ground with a ground whether or not they are projected on corresponding retinal points. A figure will not fuse with a ground nor a ground with a figure. It is for this reason that Koffka has pointed out that "the very concepts of corresponding and disparate points presupposes the concept of field organization."

Retinal position, we know, is not a determinant of the projection position in space of a point. Look for example at the facts of 'autokinetic streaming.' A single point of light moves about in an undifferentiated field. König bars in a uniform field are much harder to resolve than they are on a microstructured ground which stabilizes them. Whether two figures will fuse or not depends among other things on their relative figural strengths, as well as relative brightness, hue, distance, separation, etc. If you look at a pair of black parallel lines about 2 cm. long and separated by 10 mm., and another pair on the right separated by about 6 mm. when the left lines superpose when seen in stereo the right pair falls on adjacent but different retinal loci. Only two lines are seen. The right pair are said to "fuse" and they foreshorten and move forward closer to the observer. I have shown experimentally that they really do not fuse, that the two right hand lines are always present, that they are undergoing retinal rivalry or alternation the rate of which is an important determinant of depth, and that their apparent singleness is a resultant of the same forces which produce the phi or pure movement effect in any other case. Here the movement is forward on the z-axis rather than laterally on X or vertically on y. If now you draw the same figures horizontally it is impossible (except for one in several hundred persons) to 'fuse' the lines. Or if you leave the lines as originally in the vertical and close the ends of the left pair making it a rectangle you will find that now it is virtually impossible to fuse the two figures. The left figure is more closed, more single, has greater resistance to distortion. Even the position of a figure in a field is not determined either by correspondence or by disparity. When two circles, black on white, one 25 mm. (in diameter) and one 23 mm. (in diameter), are seen in stereo a single circle stands out in front of the nuclear plane. If now a single black dot is placed a little to the left of the left hand figure the circle will now appear rotated on a vertical axis so that the left margin almost touches the plane of the ground and the right portion of the circle extends forward at about 30° to 45°. Such positional change must be due to the presence of the dot.

In the well known illusions of reversible perspective we see further examples of the failure of the conventional theory. If we view Rubin's figure, a square of green background on which the four arms of a gray maltese cross or airplane propeller extend from the center to the corners, continued fixation of the center with the least possible eye movement will result in the shift of figure and ground. The gray strips which were at first seen as figure on the continuous green ground now become ground and the green strips become figures. In so doing they change saturation and the grays pick

up induced pink. Such changes are unquestionably functions of changes within the visual field, since the retinal patterns remain constant so far as position is concerned. Mach's book, Tetrahedron, or the Necker Cube will show reversal of perspective similarly. All these illustrate clearly the fact that with disparity and correspondence unchanged a figure will be seen at any moment in whatever orientation and position field conditions will permit. The real problem of stereopsis therefore is to be sought not in geometric measurements of disparity or in anatomical points of correspondence, but in the interplay of forces in field dynamics. Nor is this all. Vision in the third dimension is a function of animals having overlapping frontal fields and partial decussation of the optic bundles. The function evolved to assist in the control, by approximation and correction, of adjustory movements in space. Seen space and form is, therefore, a much more complex process psychologically than we have heretofore been led to believe. We may grant that the retinal mosaic is one important term in the series of events. But we must also insist that the meaning of this mosaic <u>is not intrinsic to it</u>. From the genetic standpoint there is a considerable body of evidence that the interpretations and the signaling value of such patterns of excitation mean eventually what we do about them. How else can we interpret the results of Stratton's, Ewert's and Young's visual and acoustic transposition experiments? Or how the postoperative visual experiences of the aphakic? Or how the Orange Park experiments of Lashley, Riesen and Clark on the chimpanzees reared in darkness and in acoustical deprivation?

Finally, consider the problem of the horopter. Since Aguilonius in 1613 first used the term and later Vieth, Müller, Wollaston, Tscherning, Helmholtz and others, it has meant the sum total of all <u>points in space</u> which when viewed with the binocular resting eyes are seen as single. There can only be a fixed horopter if visual space is Euclidean and if corresponding points and disparity operate as the classical theory demands. But visual space is not Euclidean. Luneberg has shown that it is hyperbolic. Köhler has shown that "every perceptual theory must be a field theory." If these propositions are true the "horopter" can only refer to a transitory feature or phase of the whole visual field, never to points in space out there. Since corresponding retinal points are the same horopter points projected upon the retinas, the same logic applies to the concept of correspondence.

(To be continued)

Psychological Optics
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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: VII

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In our effort to form the clearest possible understanding of the various phenomena of the visual third dimension it is necessary that we bear in mind the historical forerunners of the doctrine. The period from about 1840 to the beginning of the present century saw the first real attempts at any kind of a scientific attack upon the problems of depth and distance. From the first crude stereoscopes, at about the beginning of this period, there is almost no real improvement in the basic form of the instrument for one hundred years. If we recall that the neurone was not discovered until 1892 (independently by Ramon y Cajal in Spain and Wilhelm His in Germany) and that therefore any exact knowledge of the relations of function and structure in the retina was bound to be unknown, even for years afterward; and if we similarly recall that it was not until Keith Lucas, in 1914, and later Adrian and others by vacuum tube amplification photographed and described the nature of the afferent nerve impulses coming from the retina, we can begin to understand why we find certain anachronisms persisting today in our textbooks, in our thinking, instrumental design, and in our measurement and descriptive practices dealing with visual space and form.

When the first psychological laboratories began to study the problems of intensity or psychophysics, the perception of form, size, position, etc., they started handicapped by the legacy from philosophy of the sensation doctrine. Let us look at this for an instant. What was a "sensation"? Simply an elementary, and therefore not further reducible or analyzable, mental process, describable only in terms of its properties or attributes. What were these properties or attributes? Helmholtz and Hering recognized only two. Wundt added another, Titchener at least two more until we had quality, intensity, duration, extensity, clearness. Each modality had in addition its own special attributes, colors had hue, saturation and brightness, tones had pitch, volume, tonality and vocality and probably brightness and some claimed others. Significantly there was never good agreement as to either the number and kind of attributes or to the criteria of these attributes: indispensability and independent variability. The man in the laboratory became distrustful of the whole theoretical set up of the sensation doctrine because he soon found that the pitch of a tone for example, is not solely an invariant function of frequency. He found that you cannot change the brightness of a color without changing saturation. He found that if you change the intensity (i.e. the brightness) of a spot of light you change the apparent size and the apparent distance of the spot. If the spot is red, the redness is partly determined by the area of the spot, in addition to the sharpness of contours, nearness or remoteness of other colored objects. He also found that how many reds - just noticeable differences - one could see at the long wave end of the spectrum was both a highly individual matter and a function which could be changed by training. Some could see ten steps and some artists, technologists, etc., could see twice to four times as many.

By the end of the first decade of the present century it is small wonder therefore that the great Titchener, one of the founding fathers of the doctrine, should proclaim its demise. There are no sensations, said he. The sensation doctrine in 1910 had become "a closed chapter in the history of psychology."

There were many mourners at the funeral. Some of the ghosts of the doctrine are still with us. For example, in the heyday of the sensation era a corollary of the doctrine was that all attributive properties of pure sensory experiences were generated in and by the sense organs. A sense organ is a structure highly organized, differentiated and made up mainly of non-nervous tissues whose function is to serve as a detector of

specific forms of energy and to transform this energy so that it can excite the receptor or true nerve cells in the sense organ. From beginning to end the whole thing was nativistic. Space, form, color, brightness, position, motion, every conceivable discrimination was fixed in inheritance. I can well remember a course I took with a famous psychologist back in the early twenties. In it for instance, we were told that pitch discrimination is an inherited trait and that if any of us had a high pitch threshold nothing could ever be done about it since no amount of practice or training would ever change it one iota. Rarely one would find a person with absolute pitch. He could tune a violin or piano "by ear", i.e., without a pitch pipe or fork. How wrong this "information" was is attested by the fact that since good ear training in public school music has been given large numbers of children develop absolute pitch. In many technical and military enterprises the lowering of thresholds by training is a standard practice.

If a mosquito stings you on the back of your left hand, why do you not scratch your right cheek with the right hand? How do you know where the animal bit you? Nativism answered the quick and easy way. In addition to other sensory attributes the skin had what the philosopher Hermann Lotze called "local signs", or signs of position. The exact spot which received the hypodermic needle or bill of anopheles and set up a burning or itching was the only one on the whole body which had just that pattern of skin, hairs, fascia, tendons, blood vessels, lymph ducts, sweat glands, etc. Every square millimeter had its own local sign. Space was a native gift. Localization or position was there, given in inheritance, from birth on. You could do nothing about it.

This too is a closed chapter in the history of science. We are not too proud of the fact that we were so long deceived by a pure logical construct which every experiment immediately disproves. Such a doctrine could not compass the skin transplant work of Lanier and others. It could not accord with the brilliant experiments of Joseph Peterson, C. H. Judd and others. It could not stand against the three papers my students and I published on the localization of points stimulated on the skins of congenitally blind children and adults compared to the seeing of equal ages and sexes, and with the fact that practice reduces the errors of localization to a remarkable degree. There just had to be some flexibility in human behavior. If man is not adaptable, if he cannot change quickly and extensively enough, how did he ever escape the annihilation of the pestilences, wars, floods, insects and countless enemies which have sought from the beginning of time to destroy him?

No one who has read the literature of the work done on the skin any longer countenances the local sign doctrine. No one questions what the late Professor E. B. Holt of Princeton called "the educability of sensory surfaces." These are well established facts.

Now let us return to vision and particularly to our problem of visual space. Local signs and native or inborn space was held not only for the skin (contact excitation) but long before there was any exact knowledge of the nervous structure of the retina or of the nature of nerve conduction from it retinal positions were by the same thinking natively said to be correlative to spatial positions out there (distance reception). The fact that when a nasal retinal point was excited it was localized on the opposite side of the visual field was a troublesome one, but it was enough merely to point to the fact of the partial decussation of the optic bundles as a satisfactory explanation. Stratton about 1902 of course settled this once and for all. But we have with us today the legacies of corresponding retinal points and decentered images, the surviving paradigms of the doctrine of retinal local signs, the notion that in the eyeball alone do we need to look for the whole account of how we see objects as three dimensional! Only a year ago at a state optometric convention, the head of one of the largest training schools for optometrists asserted point blank that the lowering of the two point threshold for black bars (König bars) or Snellen letters from training "is nothing more than the relaxing of accommodation" and that the training of form perception is "nothing but teaching the observer to interpret a blur!" Men who heard this address (I did not hear or read it) have told me that it was likewise asserted by this authority that optometry has no function beyond measurements which can be made upon or within the eyeball. This, I submit, is an exact statement of the position current about 1880

with respect to the major problems of how we see. You measure "the stimulus" out there (uncritically defined) and you measure the functions of the sense organ (uncritically defined) and assume that what the functional integrative relations of sense organs and the entire remainder of the central nervous system, the sympathetic and parasympathetic, the endocrines and the effectors is a matter of no concern to optometry. Maybe so. It is of course, in all fairness, necessary to point out that one always has the right and the duty to define his problem and his scope. But it is also your and my privilege and duty to say whether we shall option to go along with such definition. Personally I should prefer to operate in the light of the knowledge of 1948 rather than that of 1880. I should also not like to throw out the baby with the bath water by disregarding the whole marvelous development in biological thinking in the last fifty years subsumed under the general heading of the organismal theory. Were all these men wrong - Jacques Loeb, C. M. Child, H. S. Jennings, S. J. Holmes, Walter B. Cannon, Paul Weiss, Sir Charles Sherrington, K. S. Lashley, J. F. Fulton, - the list could be many times as long? Köhler has shown that any perceptual theory must be a field theory. What happens at any specific locus within a field is determined by the relations amongst the distribution of forces throughout the field. It is interesting that the optometrist authority quoted above published a paper a few years ago in a leading psychological journal in which the surprising conclusion was stated that grounds do not influence figures. Few if any psychologists who have made visual experiments would agree. Likewise few would accept the position that each local retinal point has something about it per se which determines the space characteristic of the distal point stimulus. Retinal 'points' are of five types: (1) Identical points, which would exactly coincide if the retinas were superposed. These are the geometrical or anatomical corresponding points. (2) Corresponding points are those which when stimulated normally give rise to single vision - normally but not always. Note that correspondence is defined purely in terms of the phenomenal experience. The only possible way to tell whether two points are corresponding is to excite them either simultaneously or in close enough succession and tell what happens. If binocular single vision follows then, the points are said to be corresponding. (3) Associate points (Deckpunkte) are those whose stimulation also gives rise to single vision. Associate points may be non-homologous anatomically. It is likely that this term arose in instances like a developed pseudofovea which could still give binocular single vision. (4) Disparate points are nonidentical points, and (5) Dissociate points are points whose stimulation gives rise to double images. Some authors also list (6) Noncorresponding points. Corresponding and associate points are in most cases practically coincident with identical points and the dissociate with the disparate points. Corresponding points have generally been regarded not as being anatomically fixed but rather as physiological areas with a certain range of cooperation. Panum described them as 'sensory circles' or areas behaving like Weber's circles on the skin. If the central points of two of Panum's areas are simultaneously stimulated only single vision is seen, "and the peripheral zones of which may under appropriate circumstances do the same." Everyone at all familiar with learning or training knows that one of the most outstanding facts about stereoscopic vision is its ready and extensive susceptibility to practice effects. Likewise anyone who has taken the pains to plot carefully the regions of the two retinas which give good third degree fusion with an instrument like the Kirschmann haploscope knows that the visual areas which give single tridimensionality is anisotropic and further that the size of the areas depends upon the size, form, brightness and color of the targets employed. The surprising thing is the relatively large size of Panum's areas in certain regions of the retinas and the smallness in others. In my own case for instance I get no interference with fusing two truncated pyramids on axis 180 when the frontal plane of either the right or left target is displaced 55° by rotation forward or back from the plane position. But if the figure is tilted forward from the top or bottom as little as 6°, fusion breaks and I get diplopia.

Verhoef, Brock and others have pointed out the importance of the basic concepts of visual space particularly in dealing with cases of strabismus. The facts of size constancy are convincing enough to show that the apparent size of an object does not vary with the size of the retinal patch stimulated. The position of an object in space is certainly not a function of the retinal locus that is stimulated. The form

of any object is certainly determined only in part by the region of the retina excited. When we computed correlations between tri-dimensional space and about a dozen of the standard tests made in the optometric visual examination, all correlations, in 138 cases, tended to vary only slightly from zero. Visual space is thus something broader than mere optics. Recall for instance, the cases under which one gets psychic blindness - the interference with the back-stroke, the analogue of the regenerative feed-back input in your radio circuit. Look with Dr. Harmon at what happens when the posture of head, neck and trunk are rotated - a fact recognized by Helmholtz in the third volume of his Optics. There can be no question that space is a complex cortical integration and that the psychological factors cannot be disregarded.

No one ever sees anything on the retinas. No one ever sees anything in the brain. We see things projected in space to the place at which the total sensory - cerebro - motor field vectors position them. Hence the real question of binocular space perception is not the exclusive responsibility of the physical object, the light reflected from it, the transformation at the retinas, the afferent volleys, the conduction in the cuneus, the forward relaying to the frontal cortex, the backstroke integration and the final executant movement. It is rather the business of the whole organic circuit. From infancy we create and recreate our space worlds, just as we put on other common habits or coenotropes.

Psychological Optics

—BY—

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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: VIII

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Thus far we have considered something of the history of the problem of visual space and have taken some pains to point out the difficulty in accepting the theory that the most decisive determinants of space perception are to be found in the simple geometric conditions of binocular excitation. Hering's cover points or corresponding points are really extended regions of the retinas. It has been pointed out by Washburn and others that mere simultaneity of excitation of two such areas is in itself not enough to produce the discrimination of depth and the visual third dimension for the reason that even when this condition is fulfilled, the result may be two dimensional. A necessary condition must also be that the two eyes must suppress and alternate at a fairly slow rate in order to produce 'retinal' rivalry. Since there must be some decentration due to the separation of the eyes, such alternation, if the temporal phase is right (about one second for each eye), should produce the well known phi effect. The object should be seen first in one position then in another slightly to the left or right of the first and we should see the object as single but moving back and forth between the two positions. This can readily be demonstrated merely by fixating some object across the room and alternately closing the eyes. Each eye view is flat or two dimensional. But if we look with both eyes open and binocular alternation goes on at a natural rate, we see the object tri-dimensionally. From studies on the visual perception of motion we know that if a phi effect is produced and we keep looking at it for a little time, it is common to note that the movement from left to right on the x-axis often suddenly shifts and rotates about the zero point of the coordinate system on the z-axis, that is in the visual third dimension. Since there is no property of the retinas known to make this kind of thing possible, it is a fair and reasonable assumption that it must be a function of the cortical-motor system.

If we think of the brain as a solid conductor with Köhler and if the continued activity of a portion of the field produces a sharp conduction gradient in the vicinity of the region of high potential then as energy is depleted from this region faster than it is restored we should expect that with continued stimulation of the same retinal regions the cortical activity which is the neurological paradigm of the phi effect would rotate to the maximum position of freedom, that is 90 degrees off the x-axis. This is the z-axis position. In such case we should see the object move forward and back or rotate as if it were moved in space or as if the principal focal or nuclear plane were moved on z in front and to the rear of the plane of x.

But we still have with us the problem of depth and solidity. How does this arise as a visual attribute? Without the slightest disregard of the essential fact that the optical and ocular portion of the total process is a very important factor we still must insist with the theorem of Bishop Berkeley in the famous essay toward a new theory of vision, written in 1709, that these same optical and ocular factors alone are not enough; depth and distance would remain closed to us if we had nothing but vision alone. We must keep in mind the fact that we are seeing distant solid objects and at the same time are handling and manipulating these same objects. Their meanings, such as the fact that this particular visual impression pattern means or signifies that fact that when I handle it, I feel the back of a cube (hidden from vision) as well as sides, front and top and bottom. Thus a large part of the total pattern of my experience which I call vision is not vision at all but derives from all the other sense modalities that are active before, during and after the visual experience and, more important still, the executant movements that I make in dealing with the object which supply the groundal processes which give it

meaning. Shape, size, position, distance and to a much greater extent that is obvious, brightness and hue, derive from these ancillary and related processes within the integrating organism which establish the essential lattice or frame of reference for the ultimate gain of meaning of the central or figural process. Space, form, etc., are thus highly complex constructs which derive from the dynamic interplay of forces in the relations of the self to his surrounds.

I have tried to show in previous papers that the backstroke from the movements which are the extensions of the processes whose first terms are the adjustory and sensory instigators of behavior must be the agents of integration. When I see a thing binocularly and singly and tridimensionally, therefore, I am merely saying that the visual pattern redintegrates the trace system developed in conjunction with such sensory signals. We know that if I lose this supplementation from the effector apparatus of the body, I am form blind, psychically blind. Infants develop the ability to fixate, converge and accommodate long before they are able to walk and talk. In every account of mental development from Sully, Shinn and Baldwin to Gesell it is a significant fact that the development of any degree of competent space and form perception does not occur until the child develops a considerable amount of manipulatory and locomotor skill. All such things as perspective, lighting, cast shadows, interposition of objects, etc., are secondary to the fact that binocular visual space perception developed in the phylogenesis as a better means of assisting in the making of adjustory and protective movements. In the past years laboratory experimentation has thrown additional light on this problem. Dr. Otis D. Knight demonstrated that when an observer is trained to high levels of skill in the visual perception of forms, the motor components come to put in appearance well in advance of the appearance of the sensory stimulus, and as virtuosity is approached the character of the prodromal motor processes are highly determinative of the course and terminus of the perceptual operations. Further, Dr. Knight showed that the higher the degree of training of the subject the greater is the degree of replacement of the visual (i.e., sensory) processes and the more completely motor the process becomes. In the limiting case the perfectly trained perceiver would have virtually replaced all but the early instigatory antedromal aspects of vision with the sets, attitudes, determining tendencies of consummatory movements. Paradoxically the more perfectly we see the less perfectly we see. This is not a mere play on words. It seems to me that it is simply a recognition of the true role of binocular vision in the development and operation of the ability to develop what we must recognize as space perception. Very few of us, for example, who have not had the advantages of a good course in astronomy or astral physics, have any conception of the vastness of the physical universe. Our space is mundane. A star that is a million light years away is so far that we have no means of understanding such vast distance. We may experience an acute sense of frustration if we try to follow the mathematician as he deals with the fifth or the ninth dimension. Psychologically the shift from the second to the third dimension marks a very long step. But it is a step in a clear, known and necessary direction.

Let us return to our previous statement with respect to binocular alternation as an essential factor in stereoscopic vision. More than a year ago we were able to show that one could project through a translucent screen a vectographic stereo picture at an exposure of 0.000 003 sec., and that observers had no difficulty in seeing the three dimensional image immediately. Clearly here is a case in which if the stimulus lasts but 3 microseconds there is no time for alternation and the two eyes must be excited either binocularly or singly depending on which is in phase. Upon repeated exposure of the same picture or design at about ten second intervals no change was observed. In every case vision was clearly stereoscopic. In a control experiment when only a single right or left eye view was shown, there was never any doubt or question but that the picture was flat or two dimensional. How can we reconcile this kind of observation with the theory that alternation is necessary for stereopsis?

To answer this question it is necessary for us to start with the known facts about the differences between stimuli which differ only with respect to the one factor of duration. We know for example, that there are certain visual functions in which the end effect is a function of intensity times time. We also know that there are other functions in which there is a radical dif-

ference in the end effect depending on whether the duration of the exposure is long or short. This has been demonstrated in the case of the Aubert-Förster phenomenon. Ellis Freeman showed about a dozen years ago that area, intensity and distance are determinants of the minimum separable and the minimum visible. Recently it has been shown in this laboratory that if size-constancy targets are shown in brief exposures (ten milliseconds less), the trend of the matching judgments is toward an approximation to Emmert's Law; if the exposures are progressively longer, the constancy effect becomes definite. This must mean that with the longer exposures there is a different sort of process or that the process passes to further stages of development; or conversely that with the short exposures one gets something like Katz's reduction of the process to its simplest and most primitive terms.

If our general thesis is sound, then it should follow that even though the absolute excitation of the retinas is very brief the process is trigger-like and starts in motion the redintegration of the field structure which has come to be associated with that particular visual pattern, namely, stereopsis. From this point of view the non-visual portions of visual space should be very little dependent upon the duration of exposure, intensity, area or retinal position That is precisely what our observations lead us to believe. How otherwise could we obtain such good depth when we look at a photograph or painting monocularly? Particularly is this true if we look through a tube so as to exclude the surrounds. It is a further contention of our theory that stereoscopic vision is primarily a function not of the simultaneous excitation of corresponding retinal points with decentered images but of the structuring and organization of the total field. The visual components of the field structure may be the dominant ones or they may be relatively isolated and subsidiary to those components arising from other sense modalities and from the effector system and the trace aggregates therefrom. The particular case will be determined by the whole complex set of factors related to age, sex, training, interests, general habit structure, etc.

If we use four polarizing projectors and a metallic screen and first determine the break and recovery limits for third degree fusion for figure and for ground independently and we then set the figure at a constant decentration which gives good fusion, decentration of the ground, either base-in or base-out beyond the break point for the ground, produces doubling of the figure and loss of tridimensionality.

Similarly, under the same original relations, if the figure is decentered sufficiently, either base-in or base-out, the fused ground will double and lose its depth.

In these two cases we must conclude that third degree fusion in either the figure or in the processes which we designate as the ground is a state of mutual interdependence; that a measure of the phoria of a figural process alone is meaningless unless we are careful to specify the status of the ground in which such figure is seen. Further it is easy to demonstrate that if we produce good fusion in the figure and without altering the decentration of the ground we reduce or expand its subtend angle, we can alter the apparent size and distance of the figure. Or we may foreshorten or distort the shapes of either or both the left and right eye's images to a surprising degree before there is any interference with good third degree fusion.

More significantly still we have observed that if good third degree fusion is attained in both the figure and in the ground and we reduce the brightness of the ground to a sufficient degree by means of neutral tint filters, we can produce a doubling of the figure and loss of stereopsis. Thus we may simulate a marked prism effect simply by altering the slope of the gradient of the field forces which comprise the figure process in its relation to the supporting ground. More and more we seem to be forced to realize that such functions as acuity, the minimum separable and the minimum visible, the apparent size and distance of an object, its spatial position with respect to the observer, the horopter, in fact almost every function ascribed purely to geometric optics is subject to the laws of field structuring.

In previous papers of this series it has been pointed out that the total visual field is anisotropic. The size and distance of any object as well as its form will depend upon the resolution of field forces within the whole sensory-cerebro-motor system. It is in fact extremely difficult to conceive

how any pattern of light distributed over the retinas in the region of the maculae could be projected without change or distortion to and through the brain. The visual excitation makes sense only as an early episode in the total process which terminates in some final motor operation. If we eliminate the effectors, there is only oblivion. If we create twoness in the system there is a state of tension, of disjunction, an approach to meaningless chaos. The achievement of singleness in binocular vision is psychologically more fundamental than to see things in the third dimension. To be able to project things to their proper spatial positions with size, distance and form constant and correct is a function which can only work if the behavior organization has brought the system of visual or other sensory signals to the proper state of specialization and differentiation. Localization upon the skin has to be put on just as any other habit. Auditory localization likewise. Visual localization too is a common habit. It is a skill which we either acquire to some degree of functional proficiency or we go through life handicapped. Proof of the basic soundness of the adventitious nature of the visual space functions is found in the histories of the some 200 cases of the aphakias who have been given vision surgically. They have had to learn form, size, position, depth, distance, movement. The chimpanzees of Riesen and Clark reared 16 months in total darkness is further laboratory confirmation.

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: IX

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No other psychological function is more important to us than the organization of the individual space lattice. We may define the space lattice in terms of a geometric set of co-ordinates. The problem of deciding what kind of a geometry we shall use from the many that are available is one of very great importance. This is because much of what we do in the way of visual diagnosis and training will depend ultimately upon the basic concept that we set up with respect to the relation of the purely physical space and the phenomenal or experiential space.

The space lattice is for each of us a highly individualized matter. We define it as the general framework of space within which every part of our phenomenal world is placed. It is a four co-ordinate system. In the simplest possible case any point on this white sheet of paper can be represented by two number designations. If we scale the left hand margin into ten equal imaginary horizontal lines (y axis) and the base of the page into ten similar divisions (x axis) vertically, then any point on the page may be localized in terms of the two sets of co-ordinates. If a point p is described as (y5, x3) we erect an ordinate three units to the right of zero on x and another 5 units above zero on y and at the point of intersection of these two co-ordinates we find the position of the point p with respect to x and y. This of course is the position of a point in a simple two dimensional space system whose referential lattice is the division we have arbitrarily made by the selection of the Cartesian system of co-ordinates we employed in plotting.

If the point p is moved in any direction within the two dimensional system it generates a curve which describes the vector or path from the point p' to some other point p'' within the same lattice.

But suppose we wish to describe the position of any point in a three dimensional lattice. Then we must erect another dimensional scale (the x axis) which we must place in such a position that it is at right angles to both of the two preceding scales. This axis obviously will define the position of the point with respect to how far it lies in front of or to the rear of the nuclear or frontal plane, which may be generated by the rotation of the y axis about its origin or zero point. Now in order to describe or to tell a man in Chicago by telegraph where I want any point p to be located in such a lattice all I need to do is to tell him the numbers (y5, x3, z7) and at once he knows the exact position of the point p. By using plus and minus signs we can quickly and easily inform him on which side of the respective axes he must go in order to localize the correct position of the point.

But also it is often necessary and convenient to use still another dimension, t. This is time. Our previously defined point in a three co-ordinate system may remain in the same fixed relation to its triaxial lattice, but the whole lattice may be moving, let us say in a path around the sun.

In this case we must think and act about the point p in terms of a four dimensional lattice. All this of course is simple Euclidean geometry. It assumes that space is finite and invariant. If point p moves one unit on y, that, in such a system, is the same as one unit on x or z. But right away we see that such an ideal space system does not work very well in a "real" world. Suppose for example that we wish to measure the distances between three points of the front fender of your automobile. The fender is curved and not equally curved in all directions. If we drill small holes in the fender and drop threads to the garage floor then we may see the space enclosed in the triangle defined by the three fender points as a projection, in the mathematical sense. of the three points upon an imaginary or real set of co-ordinates upon the garage

floor. But if we stretch a string between these points to measure the distances apart of the pairs of points they will not be equal in the two systems, that is in the curved fender system and in the flat floor system.

All this is but a simple recognition that the student of the earth and the things in it who wants to describe its relations in some exact terms must at once be aware of the fact that scholars in the past have set up a variety of metrics or measuring systems. Some of these are good if we are working at one kind of problem and of no value in another. We learn very quickly that we must proceed with great caution when we measure in one kind of system and transpose our measures into another system. We also learn that if we try to use one and same system in measuring objects out there in the worked and the same metric when we talk about our own personal space experience we are very liable to make gross mistakes.

Here it is necessary to introduce a fundamental concept with regard to phenomenal or experiential space. The phenomenal space lattice tends toward neutrality. As I look out my study window I see an eight foot high green steel post in front of a fir tree. It is vertical, perpendicular to the plane of the back yard. Now I incline my head until my right ear is close to my shoulder. The post is still vertical even though when the posture of my head and neck has been radically changed, the position of the vertical axes of my two eyes has tended to keep as near vertical as they can. But the relations now of body and head positions with respect to the eyes is very different. This is but a recognition of the fact that such parts of the total visual field as assume the function of the space lattice or frame of reference will be seen as horizontal or vertical whether their retinal images are or not. This is a fact of great importance.

My tendency to return to the 'real' orientation of the space lattice is the principal reason that Stratton and later Ewert and others found that the wearing of lenses or prisms which at first distort shapes, sizes or positions will, on continued wear, right themselves; that is the relation will remain constant but the space lattice can change. If the space lattice is dispaced or disoriented the rest of the parts of the field will be disoriented to a similar degree.

As early as 1912 Wertheimer made the following interesting observation. He looked through a tube at the image of a room from an inclined mirror. This eliminated from his vision those parts of the field which would normally constitute the space lattice. He reported that the room appeared tilted and the furnishings topsy-turvy. But after a short time reorientation occurred and the room and its contents assumed the normal vertical-horizontal relations. As soon as the lattice is 'right' the objects in the field resumed their 'normal' space relations. This is a further fact of great significance since it forms the real basis of what we must do if, for example, in myopia, there is a significant displacement of the lattice with respect to the z axis. Further such fact may indicate that the measure of a lateral phoria, taken in terms to the space relations of two objects in the nuclear plane (bidimensional only) should show little or no correlation to the total space perception of an individual. This is precisely what we have found experimentally during the past year.

In functional vision some part of the total visual field is taken, shall we say, intuitively as the frame of reference or lattice. Suppose that the terrain is flat but slopes upward. The shape of the square building will look quite different in the distance from that seen when the plane of the terrain slopes in the opposite direction.

The late Professor Koffka noticed a house near Lake Cayuga at the top of the sloping shore. As he looked up at the house the building seemed to slope backwards. The sloping lawn was seen as the lattice and as such tended toward neutrality, that is toward the 'normal' position of the horizontal x axis, and since the angle between the front wall of the house and the lawn remained constant the wall was seen as if it sloped backward.

Here in instances of this kind we see another very important psychological fact of space perception. We know that individuals will differ greatly in the amount of the distortion seen in instances like the above. This is strongly linked with the individual' familiarity with the horizontal and vertical orientation of common objects as they are seen in everyday experience. This factor certainly serves as a strong corrective to protect us from making many costly mistakes in the visual estimation of space, size, distance, etc., between real objects. If

weak and inefficient it may conversely be the means of moving the space lattice to wrong orientations with the consequent errors of estimation which may be the starting points of "accidents" which are never really accidental.

The famous Köhler effect is probably well enough known that it is unnecessary here to do more than mention that if a curved line is fixated at its center for a little time a straight line seen in the same locus later will appear curved in the opposite direction. There are many other instances given in the Köhler-Wallach monograph of the space distortions of seen figures induced by the process of satiation. This work has been honored for its manifest significance for all of us interested in functional vision. The explanation has been uniformly in terms of electrical changes in the solid conduction system (the brain). In view of the foregoing it may not be amiss to point out that there is still another explanatory possibility. Such changes in size, shape, or position could be the resultants of a change in the orientation of the phenomenal space lattice. This could be conceived as resulting from a field shift induced by the change in dominance-isolation of one or another anatomical segment or from a physiological redistribution within the organic system.

We certainly must take stock of the very obvious importance of the functions of the cristae and ampullae in static equilibration from the internal ears and their reciprocal influence upon the whole visual outlook. The position sense of the observer is a determinant of the direction of orientation of his space lattice and the relationship of his visual field to that position. Even a single point of light in a totally dark room soon begins to move about, showing the well known fact of autokinetic streaming. It 'streams' or moves about because it lacks the means of the customary anchorage in space. A test object in a neutral field tends to do the same thing. That is one good and sufficient reason why the "unseen" portions of the visual field play such a highly important role in macular vision: the summation as well as the space anchorage and stabilization of the central fixation object.

It probably sounds trite to say that visual space is a tremendously complex problem. But the fact stands. If now we ask what kind of geometry best enables us to describe and to operate within the phenomenal space lattice? What kind of a coordinate system do we need to describe the visual third dimension? A long forward step has been given toward the answering of such questions by the work of Dr. Rudolf Luneberg.

Luneberg began his attack upon the problem of binocular space by a careful examination of a number of famous experiments, particularly the famous alley experiment of Hillebrant. If two strings are stretched off into the distance and they are physically parallel they will, like the railroad track, appear to converge at the horizon. In what position must the ends of the strings be placed so that they will appear parallel? Hillebrant found that they must diverge by an amount proportional to the distance from the observer. Luneberg now examined this data in no less than five geometric systems. He finally reached the conclusion that binocular space is curved; that it is non-Euclidean and hyperbolic rather than elliptical. In the geometry of Lobachevsky lines that are physically parallel diverge as they extend into the distance. This is what Hillebrant discovered occurs observationally. The mathematical picture of such lines is that of the hyperbole. One very nice contribution of Luneberg is his demonstration of a comparatively simple way to transform the set of points which define position and distance in the hyperbolic system into the simpler terms of the physical Euclidean system.

This is but another way of saying that space is transposable mathematically as well as phenomenally and we seem to have then the beginning of a method which enables us to express the relation of the 'physical' stimulus with respect to size, distance, and possibly therefore form, with the phenomenal or experienced properties of the same stimulus pattern. Thus the trend is toward the erasing of the dualism which has for so long led to no really good developments. It has been the reason for example why many persons have clung to the myth that every property of phenomenal or functional experience must be directly related to some comparatively simple physical or neurological fact, and causally and dependently determined by such fact. One often still reads that binocular space phenomena are solely due to the simple geometric optics of two different pictures

spread upon the retinas and somehow fused in a hypothetical "fusion center" in the brain. And when this too simple formula fails the tottering doctrine is amplified by the so-called secondary factors, such as perspective, light and shade, cast shadows, intervening objects, motion, etc. One psychologist was bold enough a few years ago to write a paper in a leading experimental journal in which he announced the conclusion of the whole matter of the size-distance relation was simply a matter of the amount of convergence. But when we ran correlations between size and distance and every standard measure of both accommodation and convergence taken on 138 cases by two experts, both the correlation and analysis of variance techniques clearly showed that there was no relation whatever between how much you converge or fail to converge and the apparent size or distance of an object. The space lattice of any individual not only has orientation as a fundamental property, but it also has something which we may call pitch. The Montana youth who complains that he dislikes the East because everything is so crowded is matched by the Eastern lad who finds that distance in Montana which looks like you could walk from here to there in twenty minutes actually takes three and a half hours. All of us have no doubt experienced the shock, after an hour at a good puppet show, to see the normal adults who pull the strings emerge beside the minature stage to appear at first as Gargantuan monsters. Our whole space structure must therefore be at least in part dependent on the same factors which determine all perception. This goes back to very real foundations; to the field forces which structure the cell itself, as an organized rather than an amorphous entity.

Psychological Optics
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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: X & XI

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So much has been written and spoken about the various problems of space that when one attempts to write something more about it one wonders how much of the argument is old and how much is new to the reader. At the risk of some repetition of things perfectly familiar I feel that it is justifiable to call attention again to a distinction of the very first order of importance. This is the difference between the concepts of the distal and the proximal stimulus.

Suppose I am sitting in a garden and on a small table before me there is a green pitcher. It is tall and shapely. In it are a dozen or so colorful garden flowers. The late afternoon sun is fast approaching the horizon. Part of the table is in the sunlight and part in the shadows of the row of fir trees and honeysuckles. I reflect upon the fact that if I were to make a color photograph of this scene, the orange light would radically distort the colors so that the transparency would bear little resemblance to what I am now seeing. With the sun high in the sky the absorption and reflection of light by these common objects will be quite different. Due to the fact of the perceptual constancy of brightness, color, form and size I probably do not notice any difference unless something or someone raises the issue.

As I look at the object out there I must realize that its physical properties, described in terms of the centimeter-gram-second system, are not the decisive determinants of what I see. As the wave length composition of the incident light changes the intrinsic absorption spectrum forces changes in the character of the reflected light so that long before form and position go out the vase and flowers have lost all color. But suppose we take the case of the visual perception of the object in full sunlight. We too often take for granted that what we see out there is conditioned by the intrinsic physical attributes of the object. Let us examine this notion.

The light energy density pattern which is reflected from the object and to which I respond by seeing the solid cylindrical shape of the green pitcher may be specified in the conventional manner. An outline drawing could be made and the shapes, brightnesses, hues, etc., represented in units which would enable a technician like a photoengraver to duplicate the scene. This is the distal stimulus. The distal stimulus remains the same and unchanged no matter whether I view it from my second floor study window or from a sitting position on the grass a few feet away. From the most casual consideration it must be clear that <u>no one ever sees the distal stimulus</u>.

When the physical pattern of energy is reflected from the object it reaches the sense organ, a highly specialized and mostly nonnervous device tuned to respond to the particular narrow band of the energy spectrum of vision.

Long before any real seeing takes place a remarkable change is wrought in the energy density distribution reflected from the object. If one hundred units of light energy are sent toward the eye opening the reflection and absorption of the cornea, the aqueous, the two lens surfaces, the vitreous and the passing through the several retinal layers leaves about ten of these units of energy to excite the receptor cells. In fact our best modern information has it that even a single quantum of energy arriving at the nonnervous tip of the cone initiates a chain type of reaction in this remarkable signaling system which may then produce reactions wholly disproportionate to the original energy of impact.

We are thus forced to realize that the sense organ is a first zone of energy transformation. The original pattern we started with has now lost 90% of its energy. But the losses are never equally distributed. Those portions of the scene which had a low brightness, and those hues which stand low in the

visibility curve lose more. Even up to the moment of the pick up and change by the retina of light energy into the low potential action currents in the optic bundle there has already occurred such a distortion of the fundamental properties of the original pattern that it is inconceivable if the eye itself has 'sense' how it could possibly identify the distorted pattern it receives with the physical pattern which we define as the distal stimulus.

Suppose further that we push the inquiry to the utmost then we must recognize the fact that the perceived size and color of the stimulus object will depend upon not alone its carefully mapped physical properties but also upon the nature and kind of total stage setting in which the object is viewed. This we must do because the sizes, brightnesses, contrasts, etc., in the surrounding field will produce summation and reinforcing effects or inhibiting and diminishing effects upon the central figural processes. At the retinal level we are thus forced to recognize that field structuring or field organization is actively in progress and that by the time all of the marvelous processes have taken place within the sense organ the energy pattern in the optic nerve can only be called an "image" of the object which is the distal stimulus by taking the severest liberties with the meaning of the term image.

But this is only the merest beginning. The waves of negativity which are now being virtually transferred along the optic bundles travel only a couple of inches or so until another zone of transformation or relaying station is reached. In the midbrain the impulses from the visual organ are joined by those from the ears, the skin, the muscles, tendons and from the articular surfaces of the joints. Recall that this takes place well in advance of the next great relaying station, the corpus striatum, which we are told is the first place at which the perceiver is able to be aware of the nature or name of the type or class of object he is seeing.

Somewhere or some time shortly after the sense organ, the eye, has completed its transforming operations we speak now of the proximal stimulus. It is impossible in the present state of our knowledge to do more than point out that the seeing act is a continuum and that we must therefore more or less arbitrarily select some point in the series which shall be designated as the proximal stimulus.

If it can be said that we see any object, then it is clear that the only signal which reaches the brain and the effector organs upon which we can act is the proximal stimulus. But it should likewise be remembered that when the correlation regions of the midbrain receive the volléys of afferent impulses from the two eyes it also receives at the same time all the impulses from the ears, skin and the kinesthetics and that there is no difference in the nature of the nerve currents no matter from what kinds of receptors they originate.

Beyond the striate and into the projection areas of the brain the sensory or afferent impulses from the eyes undergo another important transformation. This one has some very curious space implications. The light density distribution from the vase and the flowers falls in the two foveae and the remainder of the visual field extends eccentrically outward from this area. The figure thus excites a small central patch surrounded by the much more extensive and less sharp ground. In occipital field 17 G. J. van Heuven showed in monkeys that the projection of the maculae and of the peripheral retinas in this region is reversed. The projection of the whole extensive periphery is now found concentrated in the center and the maculae spread out over most of the area. This is precisely the kind of system needed to make possible the maximum flexibility and interchangeability in behavior. We must have a system in which one and the same type of response can be elicited by a variety of sensory signals. Yet Fulton points out (Physiology of the Nervous System, 1943, p. 331) that "a precise point-to-point relationship exists between the retina and the occipital lobe without significant spatial overlapping But suppose the proximal stimulus pattern were extended through the occipital cortex as a true geometric projection the fact stands nevertheless that in the complete absence of the backstroke from the innervation of the effectors of the body there would be no seeing, no awareness of position, size, form, etc., of any object. This has been amply proven. Purdy has shown that the motor processes transform the sensory; and I must add the conclusion of J. H. Parsons that in the phylogenetic series the evolution of all the distance receptors points to a single end: seeing evolved as a very effective mechanism for aiding in the approximation and correction of the ad-

justory movements of the body which is the very foundation of all human behavior.

How does all of the foregoing argument apply to visual space perception? In terms of the conventional theory depth and distance arise in consequence of the simple fact of Euclidean geometry that the two retinas receive patterns of light which are disparate and which fall upon corresponding retinal points or areas. But any definition of correspondence or disparity <u>must be entirely in terms of proximal stimulation.</u> This means that the real problem is the problem of organization within the psychophysical field and the factors which determine it. We cannot grant that points or lines in external space, external to the proximal stimulus, can have any direct effect on the process of seeing. The eyes themselves cannot know whether the object before them is large and distant or small and near; neither can it of itself select which pairs of points or lines on the two retinas will coalesce in determining the perceptual organization. This will depend on the transformed patterns. The origin of the forces of organization cannot lie in the retinal patterns themselves. Interaction can take place only where the processes, started in the two optical tracts by the retinal patterns, reach the brain and fit into the transforming field forces set in motion by the backstrokes from the effectors. Without the regenerative feed back input from the backstroke which is the mechanism of integration there is only psychic blindness. In the whole organic circuit then figure will interact with figure and ground with ground, and not vice versa, whether they are projected upon identical retinal points or not.

As the later Professor Koffka has pointed out "the very concepts of corresponding and disparate points presuppose the concept of organization." Koffka's view differs from my own mainly in the fact that to me the brain is the region but not the agent of organization. Further, the experiments of Jaensch, Washburn, and of Lewin and Sakuma have shown that disparity per se does not produce depth and that identity and disparity themselves are determined by factors of organization. Mach had recognized this fact as early as 1865. Motion, action carries the key to space.

Psychological Optics
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SPACE, TIME AND MOTION: XII

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Thus far in this series of discussions of binocular form and space we have tried to emphasize the fact that conventional theory of the mechanisms of our perception of form, size, position, depth and distance, etc., are too limited in scope to be acceptable. Sheer geometric optics is not enough.

If the case for depth and distance rests upon the facts of disparation in the two retinal patches that are excited then there are three very important considerations which have to be borne in mind: (1) The sense-perceptual consequences of disparity in the proximal stimuli can only give rise to the non-equidistance from the observer of certain portions of the total visual field. (2) The definite perception of nearer or farther and the amount of the relative nearness or remoteness of specific portions of the field from the plane of projection can only be obtained with certainty when perceptual data from other sense modalities can be employed. This other data is primarily motor in character. It is the essential kinesthetic backstroke without which, as I have shown in previous papers in this series, there is only 'psychic blindness'. (3) The perception of non-equidistance may be destroyed if the impressions of disparity conflicts with other perceptual impressions; if there is a disjunction between the unitary relation of figure objects to the ground; if the time of exposure is shorter than a certain minimum.

Vernon (1934) reported that in her experiments "it was found that when observers were required to state which was the nearer of two test objects seen for a short period of time in binocular vision, the variable was sometimes reported as nearer than the standard when it was some considerable distance in front of it; yet when the distance apart was smaller, the reports were inaccurate. The observer could see that the two objects were not equidistant; but during the short period of exposure he had no time to relate the disparity of the two objects to the relative disparity of the various parts of the surroundings, which were not in close contiguity with the test objects." I have underlined one phrase from Miss Vernon's quotation. The reason for this follows. Space and form as well as size and position come only after cortical elaboration and field structuring. Halstead (Brain and Intelligence, p. 145-146) has shown that in persons whose frontal lobes have been removed much the same kind of space impairment follows together with other highly important changes. Removal of the frontal lobes ... "effectively reduces to the point of virtual elimination ego control of behavior. The personality of such individuals is de-differentiated to a stage at which once again orientation and security are dependent upon the world of the senses. They are stimulus - or 'sign'-bound in the control of their motilities. Reduction of their ability for abstraction (A factor) has limited the world of symbols (relations among relations) available to them. Reduction of the cerebral power factor (P) has further increased to the extent to which their motilities are dominated by emotional or affective influences. As a result they cannot longer tolerate the psychologically "new" without undue anxiety. Valuative judgments toward long range goals give way to the rewards or punishments of the tangible present ....."

During the past year we have made several experiments on tachistoscopic size-constancy. The exposure times ranged for 10 seconds or as long as the observer chose to regard the stimulus stereo-pattern before reaching the matching size judgment to exposures of 10 seconds, 1 second, 0.1, 0.01, 0.001 and 0.000 003 second. Our findings corroborate the above arguments. With exposures beyond a critical duration, shorter than about 0.01 second, the size constancy effect tends to disappear and the matching values regress to an approximation to the geometrical optical principle known as Emmert's law.

Pouillard (1933) found that the estimation and comparison of depth and distance in the

stereoscope was often difficult when the only criterion of depth and distance was the disparity of the two stereo test objects. When he introduced intervening objects in the field or drew in perspective lines, the depth impression was improved. Earlier (1930) Kopferman had gone even farther and had shown from his experiments that disparation in the stereo views were ignored completely if they conflicted with the basic principles of field structuring laid down in Wertheimer's laws. It thus becomes plausible that the striking loss of space perception when a habitually binocular individual seeks to operate monocularly may be due to sudden change in the reduction in the total visual proximal stimulus and the consequent similar difficulty in meeting the new adjustory problem as suggested by Halstead's work and also by the experiments on the reduction of the time factor. I have tried driving my car closing my left eye. Within a few seconds there is a definite feeling of fear and distrust of my ability to pass an oncoming vehicle with enough space between us. Yet few friends know that a mutual friend who is an obstetrician and who drives the busy streets daily has but one eye. Wiley Post had no difficulty flying his plane around the world, monocularly. Every bit of evidence from studies in the field of genetic psychology points in the same direction: Space perception is a skill, learned essentially like any other set of habits. It is not one thing but an aggregate of processes, all unified in terms of the ultimate adjustory movements, which the agent must make to new and changing conditions of life. He builds a space lattice which conforms as best it can to the total configuration of both the proximal and distal stimulus conditions. One of these conditions, but by no means the only one is the fact that there are present at the two retinas two slightly different perspective views of the same scene, and it being impossible to 'fuse' them in the sense that if one is geometrically superposed upon the other they do not fit, it was traditionally assumed that depth was a sort of compromise between the incompatible situation of seeing two different pictures almost superposed simultaneously or suppressing one or the other. Or it became a working over of them in terms of the signaling value of the pattern as an early term in a series of effective adjustory movements <u>or the visual surrogate thereof</u>.

I doubt seriously that students well read in the literature of vision can take any other position. Look for example at the experiments of Riesen and Clark on chimpanzees reared for the first 18 months in complete darkness; note the slow gaining of the visual recognition of forms which to them should have been immediately recognized. Look at the case records of about 200 aphakias; look at the almost tragic consequences of the restoration of sight without retraining them to see. I cannot recall a single instance of a poor and inefficient reader brought to our laboratory who did not show low order of skill in the visual perception of forms, poor positioning, low rivalry rate, low stereopsis, poor space projection and localization, often enlarged blind spots, restricted form fields, in varying degrees and combinations.

There is perhaps no better illustration of the dependence of binocular vision upon the <u>active touch</u>, from the developmental point of view than a classical illustration first noted by Helmholtz (Physiol. Optics, III, 260.):

"I ought to mention here an experience which I have often had, as follows. If I shut my eyes and hold up my forefinger, and try to focus it without opening the eyes, the momen I do open them I see double images of it; indicating that the lines of fixation are parallel or nearly so, and therefore pass by the finger about equally far from it on both sides. But in some strange fashion, with my eyes closed, I do contrive to get a clear idea of the place where my finger is by touching the tip of it and rubbing with the thumb of the same hand. Then, indeed, even with the eyelids closed, it is possible for me so to focus my eyes that the moment they are opened the finger is seen singly. It is the same way too when I touch and feel an external stationary object."

Can there be any question of the fact that from infancy the endless handling of objects <u>while they are within the field of vision</u> has been the means of establishing the tactual-motor frames of reference which carries the meaning of size, position, distance, relation to other parts of the visual field, etc.?

All this brings us to another set of facts. While it is true that binocular visual space discriminations are heavily dependent upon the operation of other sense modalities and

on the effector apparatus of the body it should none the less be constantly borne in mind that of all the 'senses' none can compare to vision for the accuracy of localization, form perception and of serving as the essential first term in the series of useful and necessary adjustory movements of everyday life.

This, as Parsons has pointed out, is due to the hardness of the objects in the world. Light particles bounce off from them and are reflected and refracted in straight lines. Only under such condition is accuracy of localization possible. Sound and odor travel around corners. Extensity is quite different for touch, taste, the organics and kinesthetics than it is for vision.

In addition there is another still more interesting and important superiority of vision as the mechanism of space manipulation. Mach has put it this way: "What is visible also appears at first sight to be a single thing." Visual forms are from the first unitary, indivisible wholes. When we see the tree it has an inherent unity which when we touch it, taste its fruit, etc., the apparently indivisible thing at once separates into its parts. The parts may change radically as to size, shape, etc., as they change position and other relations. Vision thus is the supreme modality for synthesis, for the simultaneous apprehension of the aggregate field, for the transposition from one space lattice to another mathematically, for the symbolic elaboration which is the essence of our human culture. Visual functions of space, time and motion are thus inextricably interwoven with those human functions classed as intelligent. Mental and cultural evolution has been one of the evolution of distance receptors and their functions. As distance receptors evolved there slowly emerged the mechanism of the delayed reaction; the principal stimulus occurs now, its immediate response is the establishment of a set which some subsequent secondary stimulus touches off at some later time or place. Vertebrate animals who yet have good enough eyes are still distinctly limited in this respect. No matter how good their binocular visual impressions, the ultimate developments of space and form behavior depends upon the cortical-motor organization of these patterns as an integral, progressive continuum which terminates in adjustory movement and the backstroke of which serves as the mechanism which Dodge has so ably shown is the mechanism of approximation and correction.

To just the extent that one may write such point of view as a starting postulate in dealing with the problems of binocular space, one must realize that no longer is the nativistic position tenable. Visual space and form perception has to be learned through proper training. While it is true that the fundamental framework of the egocentric space lattice is laid down rather early in life (certainly before the 5th or 6th year) yet it is clearly evident that it is not much before puberty that the individual begins to attain the degree of skill in these functions which modern culture demands of adults.

Our modern schools and homes do little or nothing to guide and control the development of these important functions, except in a purely incidental way. We hear much talk of "training for good citizenship", "social intelligence", "leadership", "the democratic way of life" and many such phrases. It is not at all improbable or unlikely that when we realize that the early development of good sound visual skills which will greatly facilitate the ability of a child to perceive quickly and accurately all sorts of visual forms and symbols we have then given him the tools to use and will have underwritten his maximal chance of becoming all in adulthood that he can become.

Alfred Binet, the great French psychologist, pointed out many years ago that "the beginning of reasoning lies in perception." You can't solve a problem until you know and understand exactly what the problem is. When you have this, the work is three-fourths done. The rest is routine. There may be something in life more important for my children than for them to develop a fine skill in the visual perception of forms and symbols; something more important to their future welfare and success as good productive citizens. If there is, I do not know of it.

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

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Last month we came to the end, numerically, of another volume. But the numerical end is really only the barest beginning. We have approached the tremendous topic of human space discriminations visually with full awareness that we are dealing with one of the frontier problems of psychology, optometry and all other disciplines which are confronted by the problem of how we see depth and distance.

In the previous papers (Vol. 8) we have sought to show that the classical and traditional theories of visual space, even after the most careful and thoughtful review, leave one cold. In almost a century our best minds have not succeeded in getting beyond the position that the story of tridimensional vision is contained in the very simple formula: The seeing of depth and distance is told if we describe the retinal projections of objects in terms of the classical doctrines of accommodation and convergence (geometrical optics). The previous papers will show some, but not all, of the reasons why it is no longer possible to subscribe to this kind of view.

The authors of such theory, since Wheatstone's discovery of the stereoscope in 1838, soon recognized that while there was no doubt whatever as to the necessary role played by decentration of the two images, this alone was not enough to account for the manner in which depth and distance are seen. It soon became necessary to add additional terms to the equation. To the binocular parallax you had to say that space perception also depended upon chioroscuro, light and shade, cast shadows, interposition of intervening objects, movement, point of vantage, perspective and what was termed 'habit relief,' etc. It became customary to term the composite of these 'factors' <u>cues</u>. For some they served merely as secondary embellishments of parallactic vision; for others the <u>cue</u> was a surrogate, a signal which elicited <u>those</u> responses which carried the meanings of depth and distance. Even the stanchest advocate of 'eyeball' optometry, ophthalmology or psychology could not escape the fact made apparent by Wheatstone, Dove, Gullstrand, Helmholtz and scores of others that these so-called secondary factors were in certain instances capable of completely nullifying or reversing the effects of parallax or decentration.

In 1852 Wheatstone produced his refracting pseudoscope, an instrument for reversing parallax so that one sees as if the left eye were on the right, and vice versa. In pseudoscopic vision near and far objects are reversed. Solid objects should be seen as hollow; hollow ones as solid; concave objects should appear convex; etc. But if a pair of identical false faces, colored the same inside and out were viewed with the pseudoscope, one in the bas-relief and one intaglio, the result disappointingly refused to accord with the theoretical expectation. Instead of the reversal of the concave-convex positions both faces were always seen as convex. This was ascribed to habit relief or perceptual constancy of form. But it was a type of observation which could not be denied. It forced the conclusion "<u>that the stereoscopic effect occurs only when other cues to space do not interfere</u>." (Boring)

What a challenging discovery! One would naturally think that this line of thinking would be vigorously prosecuted throughout the last half of the previous century and the first half of the present one. But no. The legacy of tradition demanded that researches be designed to find the 'physical and physiological causes or correlates' of space experiences. Even today there is an irrational dislike which in some instances borders on hatred for anything or anyone who proposes to inquire into these most important and interesting problems of phenomenal or experiential seeing of space.

Scientifically trained men, the very essence of whose training should have developed in them the virtues of catholicity of viewpoint, toleration, reserving of judgment until all

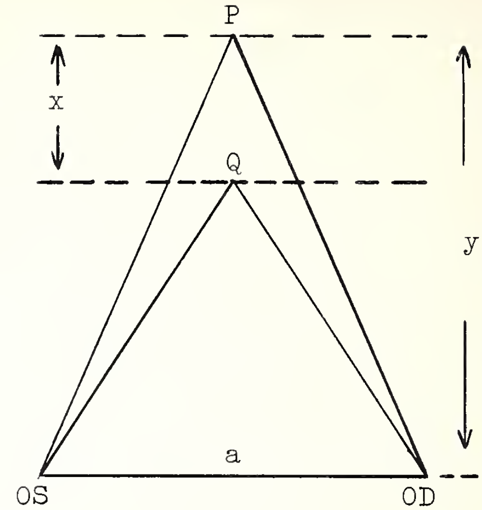
the evidence is in and assayed, are often the worst of such offenders. But of course the history of human culture is a history of the snail-like speed with which any new principle is established. Look for example at the history of the wave theory of light! The following quotation is fairly typical of what to me seems to be a most unfortunate point of view:

"We need not linger to inquire how the two images are fused mentally into a single stereoscopic impression; it is a fact of experience well known to everybody." (Southall, Mirrors, Prisms and Lenses, 1933, p. 751)

Does not this sound like the tough problem is tossed off by the assertion implied that had there been even a little time to linger then the author would have made short work of its solution? This I question. And the fact "well known to everybody" who spends a few hours in the laboratory and library is that the geometric conditions for space perception work only if the other cues to space do not interfere! When they fail, it has been customary likewise to settle the question by naming such instances 'illusions.' I can well recall the look of consternation on the face of a cocksure student when I asked him simply "What is an illusion?" and refused to be satisfied with his dogmatic attempts to answer this difficult question.

Let us then realize first that no other set of visual functions are more important to us from any viewpoint than good space perception; second, that our present knowledge of much of this province is still young, immature and incomplete and offers to the true scholar and investigator both a challenge and a promise of rich rewards.

Just as soon as we think in terms of the practical and we are confronted by the task of measuring and describing the anomalies of space perception there enters the problem of the selection of the proper metric for this description. The standard practice has been to measure the fineness of stereoscopic acuity in terms of the smallest difference in depth which can just be discriminately measured by the smallest perceptible difference in binocular parallax. The following schematic diagram will illustrate the method:



Let P and Q represent two objects in space at distances y and $(y-x)$ from the two eyes of the observer with the value of x small compared to y. Let a represent the interocular distance, which varies from about 58 mm. to 76 mm. with the mean at 65.25 mm. The binocular parallax of P is a/y radians, and of Q is $a\ (y-x)$ radians. The stereoscopic difference or steroscopic parallax in radians is then given by the relation:

$$\left(\frac{a}{(y-x)} - \frac{a}{y}\right) = \frac{ax}{y\ (y-x)} = \frac{ax}{y^2} \text{ (Approximately)}$$

Since the useful measure is usually stated in terms of angle seconds this may be obtained by multiplying the final term in radians by 206,000 seconds. When Q is just barely perceptible as nearer than P then the value of the parallactic difference in angle seconds is taken as the stereothreshold. This is the manner of computing the decentrations in the various stereometric tests. In the measurements taken on the Howard-Dolman apparatus the rod Q is moved back and forth until the observer sets it at the point which to him is just in front of P in space. Of course P and Q are represented as falling both on the midline in our diagram which in actual practice would only be met where the point of vantage of the observer was elevated above the ground plane.

Suppose now that we substitute a perfect pair of matched lenses in two cameras in place of the eyes. We make a stereophotograph of the above scene. Then when we view the two pictures in a stereoscope of the simple Brewster-Holmes type points P

and Q are now seen in projection upon a plane which lies somewhere between the points designated Q and a in our diagram. Langlands and earlier Frübose and Jaensch about 20 years ago found that the average stereothreshold was about 2 angle seconds of parallactic displacement, a value strikingly similar to the accepted threshold for vernier acuity.

It should be constantly borne in mind that these values are taken by measuring devices which almost universally disregard the 'other factors' mentioned above. Conditions which weaken or obscure boundaries, such as haze or aerial perspective, lighting, the ground structure in which the figures are seen, point of vantage or egocentric locus, movement, and all such factors may greatly diminish stereothresholds.

We should bear in mind also that it is not possible to change the apparent size of any object without changing its apparent position in space. This refers to the facts of size-constancy to be treated more fully in subsequent papers.

Finally the practical question often arises as to the distant limit of the binocular perception of depth and solidity.

The stereothreshold has been computed as an average of a large number of ordinary individuals at approximately 30 angle seconds. This value is equivalent to 0.000145 radian. When we take the normal or average interocular distance as 65.25 mm. and compute the distance at which P and Q lie in the same projection plane (zero stereopsis), we obtain a figure of approximately 1320 feet or 1/4 mile. Beyond this distance for the average individual everything is flat, theoretically.

One can begin to see some of the difficulties which stand in the way of designing and producing stereoscopic apparatus and materials for testing and measuring which will be truly orthostereoscopic. Modern projection techniques have gone a long way in this direction. In this volume we shall continue with some further papers on Space, Time and Motion. If we can add to knowledge, we add to power. Power must be paid for with responsibility. For nearly one hundred years it has been known that space perception is trainable. Only a few know how to do it well. Untold thousands need it.

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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: XIV

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Last month we presented a simple diagram illustrating the manner in which the difference threshold between two objects at different distances from the eyes is computed. This is another way of saying that it is the means of determining the smallest difference spatially which can exist between two points P and Q so that one can tell more than half of the time that P is more distant than Q. If you will refer again to the diagram on page 2, of the previous paper you will note that a was made to represent the interocular distance; y represented the distance from a to P, the more distant of the two points; and x represented the small difference of Q and P from a.

The stereoscopic parallax or stereothreshold which we may designate as n was then given, in radian measures, as

$$n = \left(\frac{a}{y - x} - \frac{a}{y}\right)$$

if now we simplify this equation, we get

$$n = \left(\frac{a}{y - x} - \frac{a}{y}\right) = \frac{ay - a\,(y-x)}{y\,(y-x)}$$

$$= \frac{ay - ay + ax}{y(y-x)} = \frac{ax}{y(y-x)} = \frac{ax}{y^2-yx}$$

$$= \frac{ax}{y^2} \text{ (approximately)}$$

The term -yx is dropped in the final equation because it is so small that we may disregard it. Since we started with radian measures if now we wish to convert the threshold into angle seconds we must multiply the final equation by 206,000* which is the number of such units in 1 radian.

This is quite simple elementary algebra. Let us now translate back into English what we have done. We have stated a law in very idealized mathematical terms. If I sit here at my desk facing westward and I look at two small crabapples upon a tree in my garden, and if I seek to tell visually which of the two is the more remote from my eyes and I disregard every other possible factor or agent which can influence that judgment, then if I multiply my interocular distance by the z-axis distance apart of the two objects and divide this product by the distance of the remotest object multiplied by itself and then multiply this quotient by 206,000, I will then know, if I repeat the experiment and move the two apples closer and closer to one another, the minimum distance apart that I can tell which is the closer more than half of the time. In psychophysical experiments we usually demand that our observer be able to answer correctly three times out of four. This is his threshold.

If we think through what we have done above, several very important things emerge. Examine again the stereoscopic law underscored above. There is no earthly logical reason why I should use such a means to tell my minimum perceptible distance discrimination. I am a 'real' person. I live in a 'real' physical world. The two crabapples are 'real objects' out there in 'real' space.

But the very moment I wish to know the answer to the question "Which is the nearer of the two objects?", then I can only find the answer by means of an operation which belongs to the realm which we designate as mental. It is hardly necessary in passing to note that the world of physics has long been highly esteemed because it is the subject which deals with "objective reality". Until rather recently it set postulational bounds for itself rigidly (and sometimes heatedly) excluding everything beyond the realm of 'real' objects and their strict mathematical relations. But space kept intruding itself as a problem for physics. And, let us note in passing that we must pay great homage to the scores of brilliant scholars in this field who, wrestling with

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* The number accurately is 206,264.8 seconds.

this problem, came to realize that the original and earlier postulates of physics as an 'objective' division of science could no longer be supported. Exactly twenty years ago A. E. Eddington (The Nature of the Physical World, p. 273) stated that "Our conception of substance is only vivid so long as we do not face it."

The two little crabapples out there have form, size, color, hardness, brightness; attributes not of the apples but of the elaborate series of biochemical and psychological events which follow upon my fixation of them. Nor is it enough merely to state that I fixate them. I have to regard them after having first done several other very important things. These things belong to the series of rational and experimental operations in me which are described as "trying to reach some sort of defensible solution to the problems of space and form perception."

A half hour has passed since I first looked at the two small apples. The sun is now low in the west. One apple, P, is now brilliantly lighted, and the other, Q, is in the shade. With this change an amazing thing has happened. P now is nearer to me than Q! But I am the same real person. Space is the same. Binocular parallax is the same. Q should still be the nearer. But it just isn't. The law has to be amended. By implication the law was stated originally as if none of these other factors such as brightness differences, figure and ground relations, or the operations within the realm we designate as the observer were anything but constant and correct. And therein hangs the story. Just when are all these things constant and correct?

Space and form perception empirically reduces to such questions as: How far or near? how big or little? to the left or right? above or below? before or behind? None of these questions are answerable in terms of the properties belonging to the distal stimulus or to the physical object from which it emanates. I say this without the slightest disrespect for all the brilliant contributions of geometric optics. It is simply a fact that any attempt at a solution of the problems of space and form purely in terms of physical optics is foredoomed to failure. There is nothing original in such a conclusion. It was better stated many, many years ago by Max von Frey, the physiologist, and much earlier by George Berkeley in 1709.

What these men concluded was essentially that vision alone, vision regarded essentially as eyeball optometry and ophthalmology regard it, is incapable of furnishing us with ample and adequate enough information as to how we perceive space, form, motion, size, position, distance, brightness, color, etc. Helmholtz saw this too. Our argument is simply one for an expanded concept. Let us deal with <u>all</u> of the factors in the equation. <u>Certainly</u> one of these factors must be the observer himself. Isn't it strange and ironical that this is the one item that has been that target of the bitterest opposition? And from the very people who presumably should be its ardentest protagonists?

Suppose the great Mach were sitting here beside me. He too would look out upon the small garden. He too would see the crabapple tree. What would he do? From his writings we already know. For it was Mach who pointed out that first we would see the tree as a whole; that vision is essentially synergic; that <u>any</u> attributes of the distal stimulus are <u>only</u> the starting points of a process of reduction and analysis; and that these are ultimately known in terms of the very nonvisual properties derived from the working over, each as he can, of the proximal stimuli.

Do things look as they do because of the proximal stimuli? We know that the apparent size of any object at a specified distance is not determined by the size of the retinal patch that is excited. We know that the shape of an object is not a direct function of the particular retinal region excited, because a square figure need only to be rotated about 30 degrees and it becomes a diamond. In fact from everything known about nerve conduction there is no evidence that the sense organ does anything more than to supply afferent volleys to the central distributing system; that from thence onward no matter what the patterning of the proximal stimulus the frontal lobes of the brain finally take over in the scanning and modulating functions and the final effector process which carries the meaning of the situation supplies the essential backstroke from these effectors without which there is only psychic blindness. If we liken the backstroke from the proprioceptors in the nervous system to the regenerative feed-back input in the radio circuit, the basis of this similarity is simple. The feed-back

keeps the circuit oscillating at a stable prearranged frequency. In its absence the circuit fades and dies. The receiver only works if it can be kept tuned to a broadcast band of the same frequency. It is the same with the nervous system. What group of effectors act and in what sequence in time depends not upon how they get stimulated, but upon the fact that at any instant only those muscles and glands can contract and secrete which are set to do so. Being set means that they must be found not in refractory phase; that the postural mechanisms (white muscles) must be relaxed; that the activities relayed through the half-centers must not throw them into inhibition; and so on. Every skilled movement is one in which the early tension type of movement has been replaced by a ballistic type, one in which the muscle contraction takes place in a fraction of a second, and the moving member swings through without the brake-action of its antagonistic muscles, guided and controlled - how? Why, by the perception of the goal or consequences of the act. By what other conceivable mechanism could learning possibly take place? And does anyone doubt that space has to be learned? The evidence is overwhelming. What visual functions are trained or transformed most readily and most quickly? Certainly. Space discriminations. What is it the untrained aphakic cannot do after he has recovered from his operation? Certainly. Make good space judgments.

Not long ago I received 138 complete visual examination records from two optometrists, one in Missouri and one in California. We ran correlations between every visual function measured in the analytical examination which might possibly be related to the observer's ability to judge size at various distances. In not a single instance was a correlation found greater than +0.10, and this is no correlation at all. Theoretically the esophore at distance should see things nearer and therefore larger. Does he? The answer is no. Likewise the exophore does not see objects farther and smaller. Space and form perception simply does not derive from those very useful measurements made to guide the professional man in lens fitting.

This is no reflection upon the analytical examination. It is only a statement to the effect that if the functions of space and form discrimination are to be measured diagnostically as a preliminary to something done about them, then the proper metric for them must be employed. The position of these papers is that neither the assay of the distal or the proximal stimuli, if either could be done, is ample or adequate enough.

Space in a "world with man left out" (Titchener) may be dismissed with a gesture. Space in a "world with man left in" is quite something else. "The idea of space for primitive man, even when systematized, is syncretically bound up with the subject (i.e., the observer). It is a notion much more affective and concrete than the abstract space of the man of advanced culture. This space is indissolubly linked with the individual personality and the tribal life and culture. It is not so much objective, measurable, and abstract in character. It exhibits egocentric or anthropomorphic characteristics, and is physiognomic-dynamic, rooted in the concrete and substantial" (Werner). ..... Physics and physiology deal only with the "world with man left out."

William Stern has pointed out that in the languages of primitive people the words used to designate space and space relations originated out of the "personal dimensions" of right-left, above-below, before-behind. These were the paradigms of the x, y and z axis of a Cartesian coördinate system.

In one African group of primitive languages "behind" as an adjective was expressed by the noun "the back"; "before" was "the eye"; "on" was "neck"; "in" was "stomach"; etc.

In a certain Indian culture if the observer faced a telephone, the dial side nearest him was called 'behind' because this side of the instrument faces in the same direction as his own back. The back of the telephone was to him the 'forward' side for the same reason. In other words the earliest space notions were egocentric, designated in terms of body mechanics and implied clearly was the notion that for the individual the zero origin of all space projections was the perceiver himself, localized at the intersection of the three conventional coordinates.

Strikingly similar is the ontogenetic development of space perception in the child. Minkowski, Pieper, Coghill, Carmichael and others have shown that in the fetal stage the arm or leg responds promptly to stimuli arising within the body as a result of specific posture, but does not respond to ex-

ternal stimulation. Stern, holds that for the infant external, surrounding space and the private, body-centered space are one and the same. Space is within the child's skin for a considerable developmental time. It is not until active touch and distance receptor surrogation develops that the 'out there' moves away and becomes differentiated from personalistic frames of reference. Localization on the skin becomes projection in smell, hearing and vision.

These are some of the reasons why we cannot accept the nativistic notion of space and form as givens - i.e. as something present in the organism as a direct function of organic structure. On the other hand space and form are species of manipulatory projective skills. They have to be learned. To get along in our culture we dare not deviate too far from the range we call the normal. Age, occupational and cultural differences do exist in these things. For physics and physiology the world of space and form is a stereotype identical for all ages, races, and cultures, forever the same. This is why vision has to be so largely a psychological problem, and the methods of dealing with it so largely psychological methods.

Psychological Optics
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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: XV

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If all human vision were monocular it is interesting to consider what some of the problems would be when we seek to construct an adequate account of the perception of space, particularly of depth and distance. The single eye can of itself give us only the direction of an observed point. Such a point may be moved forward and back on the z axis a considerable distance before the change in the size of the retinal patch excited is of sufficient magnitude to be noted. Such change must not only be large enough, but it must also change at a rate greater than a certain minimum in time for the difference to be perceived. If we seek to correlate the number of magnitudes of the just perceptible size differences with the areas of the retinal patches excited we are at once confronted with the problem of the difference between the space of physics and the space of psychology or of phenomenal experience. As the size-distance relation changes it only approximates Emmert's law under very limited and very special conditions. This is what is known as size-constancy.

As an object recedes into the distance it does not diminish in size as much or as rapidly as it should if size and distance were determined by the areas of the retinal patch. Far objects are seen much larger than the physical conditions would predict; and near objects normally are seen much smaller than they should appear.

Such statements naturally imply that there is some specific distance from the observer at which the "real" object will be seen as possessing its "real" size. And immediately when we seek to ascertain just where this position lies in space we meet a definite difficulty. This question will concern us later in this series. For the present let us limit our inquiry to the fact that if a point moves back and forth on the line of sight of the single resting eye the only change will be in the size of the blur circle, and, as Helmholtz has pointed out, providing the change does not exceed the length of Czermak's line of accommodation the amount of variation of the blur circle will be absolutely imperceptible. All that can possibly be supplied by monocular vision is the apparent direction of the line of sight.

Czermak defined the line of accommodation as "that segment of the visual axis where, for a given state of accommodation, an object can be seen without being indistinct." As distance from the eye increases the length of this segment increases, becoming infinite when this distance is very great.

At great distance an object can change its distance considerably with but very slight alteration in the position of its image. When accommodated for infinity the blur circles of objects as close as ten to twelve meters are so small that distinctness is not seriously impaired. When the accommodation is for near, however, a slight change of distance will cause the object to be entirely out of focus.

These observations were made by C. Scheiner in his famous experiments, made just about 300 years ago, on the monocular viewing of a pin or match through a pair of pinholes in a card. From them came the facts of crossed and uncrossed disparity. The troublesome problem of the inverted image and how we came to see the object in the correct orientation had to wait for the brilliant experiments of G. M. Stratton near the opening of the present century.

It is perhaps enough for us here to note in passing that it took a long time for us to learn that sheer optics alone could not possibly give us the answer to the problems of space and form perception; that the 'world with man left out' of physics could not render the account of experiential space of the 'world with man left in' of psychology. It is of interest and of some concern that certain scholars are still valiantly trying to render some sort of an adequate account of space and form perception limiting their accounts to the events at the retinas. Others go a step farther and talk of the projection

of the retinal patterns to cytoarchitectural fields 17 and 18 and stop there. In either case the whole process is one of light patterns transformed by the retina into afferent volleys of slow moving virtually transferred ions spread out within the brain. For the clear 'explanation' of form and distance perception we are taken to the dark continent of the hindbrain ..... and left there! But we know that even if all their statements were true, we still could not see without the guiding and controlling functions of the nonvisual mechanisms to the body. Without the backstroke there is only psychic blindness.

Let us return again to the single eye. A point of light from a distant position is twenty degrees to the right or left of the axis. What does the eye do first in order to see? The extrinsic muscles, the muscles of the head and neck, or the back and trunk move to align the incoming beam to a position of centered focus. How does the eye know when it is in the best position for seeing? It 'knows' in the same way the insect reaches in flight its proper orientation toward a point of light; the frequency and intensity of the beating of the two wings is a function of the differential brightness reaching the two laterally placed eyes. Through complete decussation the tonus and the contraction phases of the wing muscles on the opposite sides of the insect's body finally are brought into the best possible approximation to a dynamic equilibrium; flight is straight to the light. A pilotless airplane controlled by radio, radar or photocells may utilize the same type of feed-back control. There are very many mechanical analogies of the backstroke mechanism. The significant thing is that for any vision at all to be effective we must first have the intact action of the very important motor apparatus for bringing the sense organ into the optimal position for stimulation. If the backstroke mechanism is injured or diseased or impaired in any substantial way, then the eye 'hunts'. It swings saccadically back and forth across the true position, and may never really reach close enough approximation to equilibrium for the effective visual act.

Suppose I reach for my pipe before me on the desk. Why does my hand not fall short of, or overshoot, the mark? Simply because the mechanism of control is not only the proprioceptive components from the skin, muscles, tendons, joint surfaces and from the eyes but from the joint agency of all these cooperatively in bringing the prehensile organ to rest and equilibrium at the right position. Think of the case of what the neurologists call 'purpose tremor' or better still think of the complete blocking of the executant act in what is termed 'abulia' - the complete inability to instigate and carry to completion even a simple type of voluntary movement.

Not only is the backstroke the mechanism of centering or orientation, but a second most important function is in synchronizing and synergizing all the divergent frequencies of the nerve volleys. <u>Some</u> way has to be found to reconcile the <u>fact</u> that the spaces and distances of the skin, ear, eye, muscles, etc., are not the same things by any means. Seldom are the kinesthetic inch and the visual inch the same. But our adaptive movements, the terminations of all sense-perceptual experiences, have simply got to be resolved into a <u>single</u> and approximately accurate system. <u>It is</u> contended here that this is one of the primary functions of the backstroke.

Moreover, how do I know that this is <u>a</u> pipe... my particular pipe? If the present set of visual processes alone cannot give me satisfactory answers to these questions then we must look to the next stage. This is the fact that all the impulses afferent from all the different modalities are relayed forward to the frontal brain.

Here the pattern is supplemented by the host of memory and attitude traces. Here the frontal lobes complete their scanner and modulator functions. What decides the kind of movements, speech, writing, we shall make? Proofs have been adduced previously in these papers to show that the brain does not send specific 'messages' to specific muscle groups and arrange the temporal order of their contractions. The most probable answer to the question raised above is that the central mechanism 'hunts' the motor outlet <u>set</u> and ready to go. This being <u>'set and ready'</u> often depends upon what we have just been doing previously; upon the action of the postural regulating mechanisms (white muscles); upon the sets, attitudes, purposes, desires, intentions, etc., which we carry as the linguistic surrogates of delayed reactions. Can it be that the backstroke, the proprioceptive maintaining stimuli, are chiefly responsible for the final outcome?

There are powerful arguments in support. Titchener once said that meaning is kinesthesis. What anything means to us is what it is used for, what it does to use, what we can or may do with it. Now in every perception the frame of reference, set, attitude, purpose, intention precedes the active process of visual impression and the ultimate adjustory movement. Were this not true it would be difficult or impossible to build a theory of learning or the transformation of sense-perceptual experiences and adjustments which could be defended. The end product of the distance receptor processes we call seeing is the attainment of some sort of tolerable or acceptable equilibrium state.

The term set thus refers to a predisposing set of forces within a field such that as a rule any stimulus which comes at the right time or in the right relations becomes good enough to instigate the process. Thus if the set is of sufficient strength and has been sufficiently habitized there is a gradual reduction in the necessity for a clear or sharp stimulus signal. The process becomes more generalized and abstracted; it returns to the early state of mass action, from which specific movements are individuated, or in perception to the general and abstract first states which become specified through training and experience. It is probably from this that a philosopher once said "tell me what you like and I will tell you what you are."

Set is not only a powerful determinant of behavior. It is also a fundamental determinant of all of our perceptions of space, and form. As an example we may cite the observation of Sinsteden. He looked at a windmill projected against the bright evening sky. One half was silhoutted as a uniformly dark object on a bright background, its outline being merely visible. Sinsteden noted that as he looked at the windmill the wings of the mill seemed to go round first in one direction and then in the other. When he looked at it in this fashion he was unable to tell whether the front side where the wings were or the back side of the mill was towards him, or whether he was looking obliquely at the wings from in front or from behind. If he were seeing it from in front the side of the wings next the mill ought to have been the one nearer to him in perspective. But if he were seeing it from behind this side should have been the one farther from him.

As Sinsteden interpreted the observation the side of the wings next to him appeared to go up or down as they revolved, and so by simply changing his ideas of his own position with respect to the object he could reverse the apparent direction of motion of the wings at his option. If he imagined he was standing on the other side of the mill the change could be induced immediately. The moment the visual impression accords perfectly with this idea, the idea assumes the role of a 'real' visual perception.

W. R. Miles pointed out the same thing with the ordinary lawn sprinkler. Set yourself to see it rotating counterclockwise and that is the way you see it, or vice versa. Similarly the 'illusions' of reversible perspective. But the basic fact is that it is not a mere matter of which lines in, say, the chimney corner figure we pay attention to. Even if we maintain complete fixation, the reversal takes place just the same. Look for example at the well known Rubin figure of the four bladed propeller on a circular ground. Here unquestionably the rate of alternation is a function of the interplay of forces which define figure and ground. Figure can remain as figure only so long as the constituting forces remain in the proper direction, balance, etc. Self imposed instruction can operate here the same way it did in Sinsteden's case.

Oddly enough if we time the reversals in the typical case - such for example as the Rubin figure - the length of time the figure can be seen as figure gradually diminishes. If we plot the logarithms of these times against the number of the reversals we get a perfect straight line.

This can mean but one thing. The process must be perfectly regular and according to natural law. The hysteresis effects in protoplasm effected by activity are gradually reducing the time the figure can remain as figure. The redistribution of the forces in the visual field are as they should be; according to law and order.

In the binocular perception of the third dimension the left and right eye views may be presented in sequence rather than simultaneously with no impairment in the perception of the third dimension. Similarly the third dimension can be seen where the time of exposure is as short as 3 microseconds.

In the formulation of any satisfactory the-

ory of visual space and form all the known facts must be capable of fitting into the design of such theory. Every perceptual theory must be a field theory. Every perceptual theory must be a motor theory. The only animals who need be concerned about space and form are those who in order to live must move about in space. The greater the speed of such movement the finer must be the dynamic organization of the organic circuits which control and regulate the manipulation of space and form.

Psychological Optics
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OPTOMETRIC EXTENSION PROGRAM

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It is time now before proceeding farther with the problem of the visual perception of the third dimension to review a few facts with regard to perception in general. This we must do before we attempt a formulation of the mechanism for three dimensional space perception which fits the largest number of the known facts about visual space.

In the very beginning of the efforts to study man's functions scientifically, not more than a century ago, scholars found the ready made doctrine of sensations already current as a legacy from the philosophers. Sensations were the simplest and most primary of the mental elements. They were elements because they could not be analyzed into anything simpler than themselves. At first they were defined in terms to two attributes: quality and intensity. These were the only two ways in which these elementary processes differed from one another. They were regarded as highly important because all other mental processes were constituted out of these simple elements, plus images which were the residual aftereffects of prior sensations and simple feelings of pleasantness and unpleasantness. There was nothing in mind which did not have prior existence in sense.

Many years of study by able scholars of sensations revealed that sensations, if they were real processes, had to have additional attributes. They had to have some <u>intensity</u> since no one could ever become aware of any process below the threshold. They had to have some amount of <u>duration</u>; any kind of existence has to exist in some finite time; they had to have at least sufficient <u>clearness</u> in order to be recognizable, since the state of complete blur was tantamount to virtual non-existence; moreover, they had to have some degree of <u>extensity</u> in space. Each separate modality had in addition its own individual attributes. Colors, for example, had hue, saturation and brightness. The criteria of all such attributes, this is of the defining properties, of sensations were two: indispensability and individual variability. You could not have a sensation if any one of the attributes were zero. Each of the attributes likewise existed independently and in its own right.

But just as soon as experimentation started it became increasingly more and more difficult to adhere to such a theoretical formulation. If you changed the brightness of a colored light you changed also its saturation. If you changed the intensity of a spot of light you changed also its spatial position. The attributes were found not to be independently variable.

Whatever success scholars achieved in the analysis of complex perceptual processes into their constituent sensory elements was certainly negatived by the simple fact that this process was not reversible; the complexes simply could not be synthesized by the addition of the sensory elements. In fine the history of experimental psychology records that the sensation doctrine had to be abandoned. It had been tried and found wanting. Its demise marked the first decade of the present century.

For most thinkers perception absorbed sensation. No one denied or denies that the eyes receive the energy impacts from light reflected from common objects that we see. Warren proposed that in the interest of clearness and better understanding we use the term <u>impression</u> to designate the above fact.

But the light impression is recognized merely as the fact that at any moment the eyes get stimulated by an impact of energy and that this starts a series of changes within the organism which are only in small part determined by the <u>physical</u> characteristics of the stimulus. What we perceive, understand and act upon is quite another matter. A chimpanzee reared in total darkness for the first eighteen months of its life was found by Riesen and Clark only to be able to recognize its nursing bottle, its sole means of existence, after some 83 feedings

when the bottle was presented clearly in the animal's field of vision. We have to learn to see space and form.

Goodman did the same thing with rabbits (Amer. J. Physiol., 1932, 100, 46-63). His animals which spent their first 6 months in total darkness showed "no discernible changes in the visual pathways" neurologically. But when first taken into the light they "walked on a broad base with the forelegs widely spread, the neck protruding at full length in advance of the trunk and the snout held so that it almost touched the ground. They did not avoid obstacles placed in the path, but depended upon cutaneous, olfactory and auditory cues, sniffing continuously and walking so that the snout vibrissae remained in contact with the edge of the wall. When placed on a low box they would not jump even a short distance to the ground." Senden, in his study of about 100 cases of persons born blind but restored to sight surgically (Raum- und Gestalt Auffassungen des operierten Blindgebornen vor und nach der Operation, 1932, Barth, Leipzig), found substantially the same thing with humans.

Perception, of whatever thing, process or relation, can never be limited to the present process. The impression is at once supplemented, elaborated or foreshortened by the organized sets of residual traces remembered from previous adjustory reactions made to these and similar situations. Boring (American Journal of Physics, 1946) said that "the purpose of perception is economy of thinking. It picks out and establishes what is permanent and therefore important to the organism for its survival and welfare." Surely. Any animal who fails to diagnose correctly the demand of the moment and the ultimate demand of his changing environment soon becomes a dead animal. He must decide upon and take the expedient course of action. To do this he must perceive both the antecedents of the present situation and weigh the probabilities of the consequences. In no case is a perceptual process decided by the pressures of the moment. Set, attitude, intention, purpose, desire enter into the picture. Let us take a typical case. A new and strange object lies on a table in the laboratory. The first inspection is a process of noting its form, size, position, etc., as the beginning of the search for meaning. One speculates as to what it is; what group or class it belongs to; its similarity to previously known objects; what its uses are. While all this is going on one may pick it up and on observing that it contains a lens system, raise it to a viewing position.

Judgments will be formed as to its functional properties, value, design characteristics, possible improvements, uses, etc., and the amount and kinds of such processes will always be largely determined by the previous training, interests and the present purposes of the observer. We always see more and less in anything than just the mere aggregate of its physical properties. This is another way of saying that the schemata or organized frames of reference largely determine the ultimate meaning of the thing and so set the course of action. This, of course, is why perception is so much an individualized matter.

Bartlett has called attention to the fact, from his extensive experiments, that differences of temperament will show themselves in one type of extrovertive and imaginative individual who will go far afield in his elaboration of the perceptual process. On the other hand the person of the opposite type will maintain rigid adherence to those things immediately given. His account of what he sees is like Wordsworth's Peter Bell for whom the

"Yellow primrose by the river's brim
A yellow primrose was to him
And nothing more."

Perception is projective in the sense that it looks forward and anticipates future contingencies. This is best seen, perhaps, in the facts relating to invention, creative design and problem solution. There is no question as to the fact that such functions are capable of expansion and of increased efficiency through training and practice. One large corporation maintains a sort of postgraduate school for its young engineers. Here they are given a problem. Often is one which calls for a considerable amount of the type of thing in which the young man must synthesize and create some novel means of producing the desired end result. One such problem for example was to design a typewriter for writing music. The primary object of the school is both to discover those who have the aptitude and the love of this type of 'free' work and to watch the modes of attack he utilizes.

If a problem in mathematics is presented to one it is well known that the first and most

important thing in leading to its solution is the accurate perception and understanding of the precise demands of the problem. Just as soon as one sees clearly what the real problem is, then the solution is inherent; the work is two thirds done; the rest is easy.

Now let us apply some of the above facts to our interest in the visual perception of space. One attribute of every visual impression is that of extensity. The term extensity has two distinct meanings. One refers to the sheer physical fact that the objects in the perceptual field have size; they fill up so much of space; they are partly hidden by intervening objects of such and so size; they have position; they are near or remote. The other meaning of extensity refers to the phenomenal fact that to each of us, according to his organized schemata, the perceived size, distance, etc., of any object will depend upon the implicit scale position to which the perceiver assigns the object. In a typical psychophysical experiment if a 40 gram weight is to be hefted and compared to a weight which is half a gram heavier or lighter, the error will be changed in direction and amount if we have had him lift a 400 gram weight before making the above comparative judgment. The brightness of a patch of gray paper will be judged in terms of the relative brightnesses of its surrounds. These and similar instances show us that the perception of the properties which we carelessly assign to objects are very strongly influenced by what Helson has called adaptation-level. Temperature for example is a physical continuum; psychologically it is not true to say that warm-neutral-cold represent positions on a single continuum. Several years ago I showed experimentally that 'neutral' distilled water (that is water having no warmth or coolness) on the tongue or on the skin of the hand could have any physical temperature between about 22 and 42 degrees Centigrade, depending upon whether the series ran from cold to warm or from warm to cold.

Space judgments are influenced in the same way. I well recall my first visit to the overwhelming big spaces of Wyoming and Montana. Since then on several subsequent trips to those regions the plains and the mountains are not nearly so big.

When I view any object binocularly, what determines its position in space? In the past it has been the custom to talk almost exclusively in terms of the degree of convergence and of accommodation. Helmholtz thought, for example, that the afferent impulses from the ciliaries and the extrinsic muscles of the eyes were the 'cues' to size, position and distance. Were this theory true we should expect to find an almost perfect positive correlation between the measures of, for example, phorias and ductions and the judgments of the size and distance of objects. When we ran such correlations on 138 cases, the values of the correlations approximated zero. The more one studies the possible answers to the question raised above the more one is forced to conclude that the primary determination of spatial and temporal characteristics of objects within the visual field are not to be found in any attributive property of the objects themselves. The patterns of impression are actively worked over and are projected to positions in space which are determined by the resolution of the forces within the visual field. All seeing is essentially a signaling process. The meaning of size, position, distance, etc., is a contribution of the active perceiving organism in its effort to achieve a satisfactory adjustment to the behavior demand of the new and changing geographical environment. To be able to render accurate description or drawing of a common object the untrained observer must make a number of approximating and correcting attempts.

Space and form discriminations are built up by a process which runs a course in time. With increased age and experience this process becomes foreshortened just like any other learning function. To perceive is thus to arrive at a position to deal effectively, quickly and with the least expenditure of energy with the situation which at first is an unknown, or for which those processes which were going on at the time of appearance of the impression are now no longer adequate.

The functions of space and form perception are trainable to a marked degree. A graduate student in English comes to us because he had developed a reading problem. He shows us a 14 diopter lateral phoria, at far point and almost as much at near. He is given 8 training sessions because he had no fusion amplitude at all. Then he has a ten day rest after which he returns. Today he is ortho.; he has a more than ample range within which he can maintain good third degree fusion; he announces that his discomfort, headaches, etc., are gone. Now we are ready to take

the next step in what I choose to call sequential visual training. This is all commonplace. It is done every day by men and women who do a good job of training. It clearly signifies that the positioning in space of a target seen binocularly on the x axis can be transformed through training.

The same is true of the z axis function (position of nearness or remoteness with respect to the observer). Köhler has shown that the figural aftereffects in the third dimension exhibit even sharper effect than those in two dimensions; that objects can be displaced because of prior satiation either forward or back from a plane of projection. There is every reason why the size and apparent distance of an object, that is the position of the nuclear plane of projection, can be changed through training. Is it not of interest that a lens which has marked effect upon the area and contour sharpness of the retinal patches excited yet has within wide limits no effect upon apparent size and distance?

It is well known that the pure geometrical facts of the binocular parallax alone are not a safe guide to our perception of depth and distance. The perception of the surroundings of the test object plays an important part in the estimation of brightness, size, form, and distance. What occurs in the paracentral and peripheral portions of the visual field strongly influences the perceptions of space relations. In Kopferman's experiments for example it was found that disparities could be disregarded if they conflicted with configurational factors. Different parts of a line-figure were drawn on glass slides and were presented at differing distances from the observer so that the parts of the pattern appeared contiguous. If the parts formed a connected whole the pattern was seen as a single two dimensional whole in one plane. A box figure was seen in three dimension but if the lines were not well articulated the observer saw them as disconnected parts situated in different planes. Tridimensionality thus he concluded must be dependent upon structural field relationships and not upon the disparity of the constituent parts. Also, habit-relief, that is the observer's previous knowledge of the spatial surrounds strongly determines what he perceives. A good stereo of a landscape reversed in a stereoscopic instrument is generally perceived as in normal and not reversed or pseudoscopic perspective. In the staircase - cornice illusion of Schroeder, Pierce observed that of those who habitually saw the figure monocularly as a staircase, 77 percent still saw it as a staircase when it was presented stereoscopically in reversed perspective to appear as a cornice.

There seems to be no question that binocular solidity, depth and distance is a function in which the visual datum has to be worked over, structured and organized as a part of the rational and intellectual processes of the individual's total space schemata. The ease and accuracy of such perception depends upon "the continuity, coherence, and good articulation of the configuration as constituted by the factors of form, size, brightness, etc.", and by the constitution of the visual fields, i.e. the retinocortical-motor system, of the observer at the moment. It is for this reason that the taking of adequate 'skills' measures of binocular space perception is of such importance. And it follows that one of the first steps in training must be the restoration of the normal unity and coherence of field organization. Rivalry, phorias, ductions, stereo amplitudes, etc., must be prevented from blocking the quick and accurate perception of form, size, position, distance, motion. Lenses alone can assist but cannot do the things which must be done by proper training.

Psychological Optics

—BY—

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SPACE, TIME AND MOTION: XVII

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There can be little question that the valid and accurate perception of space relations necessitates the proper functioning of the sense organ. It is here that the signal which is a distribution of energy within a field begins the first stages of organization and structuring. Within limits, for example, a binocular pattern is superior to a monocular one; lighting, color, perspective and parallax all conduce to the delivery to cytoarchitectural zones 17 and 18 transformed signal patterns. At this stage it is not likely that there is much resemblance between the spatial distribution or the contour of the energy distribution found shortly earlier upon the excitation of the retinas.

It is not without significance that many persons hold the view that since zones 17 and 18 comprise a large segment of the 'visual cortex' it is here that the conscious and isomorphic 'seeing' of objects takes place. Such a view gains support from the experiments of Klüver (1936) who showed that in the monkey, after bilateral removal of the occipital lobes, 'there appeared to remain no serviceable vision' for common and familiar objects. Brightness discrimination was found to remain however by Hilgard and Marquis, studying dogs, employing a conditioned response method.

These investigators (1936) concluded that brightness extents of sufficient intensity to make the animals aware of shadows passing across the visual field were observed in their experiments.

Klüver showed that monkeys without the occiput could not discriminate between different sizes or brightnesses. Performance of learned acts was better under scotopic than under photopic conditions. In the striate area the projections from the macula cover large portions of fields 17 and 18 and are spread out over these areas in distinction to the terminations of the peripheral fibers which are concentrated in the middle region (van Heuven, 1929). It is maintained that any injury to or lesion in this area is accompanied by a proportional impairment of object vision. Marquis (1934) claimed that destruction of the region results in the human in total and permanent blindness. Lashley and others have produced works which cast doubt upon this statement. Fulton, for example, points out that evidence of clinical nature is only present upon 9 cases. But without question the role played by the occiput in space and object vision is a fundamental one.

But the trains of afferent volleys from the visual organs do not come to the cortex unaccompanied. There are the all important kinesthetic, tactual, auditory, etc., impressions, also. All are relayed forward to the frontal regions and thence back, down and into the effectors, which in turn provide the organizing and integrating and directing agency of the backstroke, the analogue of the 'regenerative, feed back input' of the tuned radio circuit.

With something more than mere speculation we can be fairly certain that vision at the occipital level can hardly be farther along in the full development of the process than the stage of the generic object. I know that the object in front of me is a pipe. Without the frontal cortex I do not know that is my pipe, that it was a present from a group of friends, that it cost $12, that its wood came from Algeria, that it was baked 6 months in an electric oven before it was formed, etc., etc.

All of the products of the memory traces from the past and the transformation of the present and future meanings of objects which give them reality, vitality and empathic significance would be absent if we had nothing but the hind brain.

No visual discrimination of space or form is complete until the whole temporal course of the process has been run. This of course means that the movements or acts made in response to the excitation of the retinas <u>is an integral part of the seeing act</u> and that the backstroke supplies the means whereby

approximation and correction, and the setting of the stage for subsequent experiences is attained. Did we not show in previous papers that McDougall, Head and Rivers, and Goldstein found that if the afferent movement-produced volleys are blocked there is 'psychic blindness'? In fact every portion of the entire sensory cerebromotor mechanism must be structurally and functionally intact if behavior is to attain and maintain its maximum proficiency.

In the light of every known consideration it must be concluded that we cannot and do not 'see' with the 'visual' cortex, that is with the architectural fields 17, 18, and 19. Vertebrates and particularly man has built an astonishing culture because he has taught himself to design and use tools; has developed intricate sets of signaling symbols and mechanisms for communication and for the foreshortening of action systems. He has done this only because he has been able to evolve distance receptors and effector systems which make possible such things as delayed reactions; he could abstract and generalize; he could perceive and solve problems by surrogation. The higher in the evolutionary scale the greater is this personal making over of the raw-products of the sense organs and the less is space and form vision determined by purely optical considerations.

What does the frontal cortex contribute to vision? Several lines of evidence contribute to our better understanding of this problem. Let us examine a few typical ones. First, consider the work of Senden (1932) who studied the space and form perceptions of persons born blind but restored to vision by surgery. Some 100 such cases are on record. Many who read this paper will recall the vivid description of his own experiences by Mr. George Campbell, typical of Senden's report. The sensory deprivation produces an arrest of development (1) which can only be repaired in part by careful and appropriate training; (2) which produces clear cut behavioral, personal and social changes, and (3) which probably can never be made the equivalent of a normal growth and development. Halstead has pointed out that no other sense modality plays such a role in the functions of the frontal brain as vision. Visual space for example is far more accurate than that from touch, hearing or smell. So the person deprived of vision from birth develops and lives in a world quite different from the seeing. Our own experiments several years ago, (Journal of Genetic Psychology, 1930) showed that there are marked differences in the spatial sensitivity of the skins of blind and seeing children and adults. Visual developmental deprivation is thus not alone a loss of vision.

There have also been several important experiments in which animals have been reared, for prolonged periods following birth, in total darkness or in soundproof surrounds.

One of these was reported by Goodman (Amer. J. Physiol., 1932, 100, 46-63) who raised rabbits in darkness for the first six months. From this work we learn that:

"Complete lack of optic stimuli in rabbits from birth to six months of age results in no discernible changes in the visual pathways, does not prevent the lid and pupil reflexes from responding to the first stimulus of light, or the animal from quickly learning to respond to visual stimuli in regulating its behavior; nor is there any indication that the presence of the peripheral sensory visual field is a factor in the development and differentiation of the optic system in the rabbits, or in the ability of that system to function." When the rabbits were first taken into the light at the end of five months the postural reactions were interesting. The animal walked on a broad base with forelegs widely spread, the neck protruding at full length in advance of the trunk and the snout held so that it almost touched the ground. It did not avoid obstacles placed in its path, depending on cutaneous, olfactory and auditory cues, sniffing continuously and walking so that the snout vibrissae remained in contact with the edge of the wall. When placed on a low box it would feel the edge with its front feet, but would not jump even a short distance to the ground. Experiments showed that the olfactory sensitivity was much greater in these rabbits than in rabbits raised in normal lighting conditions. During the first ten days in the light, the animal advanced considerably in its ability to avoid objects. At the end of one month the rabbit would follow with its eyes hand movements made two feet from it and would turn to avoid sudden movements of objects.

Riesen and Clark reared chimpanzees for the first 18 months in darkness. Many readers have read the report (Science, 1947, 106, 107-108) or seen the film. When brought into

the light the animals "were, in effect blind". The first blink to a threatened blow came consistently only after 48 days when the animal in question was 22-1/2 months old and had spent 570 hours in the light. Recognition visually of the nursing bottle came only slowly after the 33rd feeding and reaching for it only after the 48th meal or 16th day in the light. Other animals were even slower to learn visual functions. The authors conclude that "visually mediated learning" came only after 50 hours of exposure. Senden's results showed for man even longer periods. A long period of development "is essential for the organization of perceptual processes through learning."

The significant fact however is that animals of Riesen's and Clark's control groups reared in normal visual environments learned spatial localization, recognition of objects, avoidance and withdrawal from threatening or harmful stimuli in often a single vivid experience!

Quite important, also, to our thinking about the mechanism of our perceptions of space and form, are the conclusions from a dozen or more workers who have studied experimentally the effects of frontal lobotomies, in animals, and of the injuries or destruction of the frontal lobes in man.

Stanley and Jaynes (Psychol. Review, 1949, 56, 18-32) have recently summarized the principal findings from many of these experiments. Removal of the normal functioning of the frontal lobes produces:

(1) Hypermotility or Inertia. The animals pace back and forth restlessly or else sit immobile and indifferent to the surrounds." Vision seems to play a major role in the sensory control of hypermotility." Darkness reduced the total amount of activity in monkeys.

(2) Increased Food Intake (Hyperphagia). The animals eat, like feebleminded humans, without any increased hunger. Klüver fed grapes to a bilateral frontal monkey. "If a second grape was offered before the first was carried to the mouth, the monkey dropped the first grape and took the second, and so on until the floor was littered with dropped grapes and the animal had not eaten a single grape."

(3) Alterations in emotional and social behavior. The animals "persisted in the face of repeated failures of the delayed reaction test", "lost preoperative shyness and fear of man", "showed no grooming or affection toward its companions", and "behaved as though they were inanimate." "It would walk over or on" other animals "if they happened to be in the way and would even sit on them. "It would openly take food from its companions and appeared surprised if they retaliated, yet this never led to a fight" since the author reports the animal seemed "merely to have lost its 'social conscience'."

(4) Difficulty in habit alternation or reversal. Animals must form many habits of the type that you eat and avoid shock from the left food box if a white card is behind it but out of the right hand one if the card is black. The cards were shown as in the delayed reaction experiment. Normal monkeys easily learn the habit shift. The operated ones do not.

(5) Poor performance on seriation problems. If a box to be opened in order to eat required pulling a rope, turning a crank, stepping on a treadle in order, they would persevere on one of the mechanisms which had already been opened.

(6) Poor performance on the multiple-stick-and-platform problem. Tool using, by raking in longer and longer sticks in order to reach food from an opposite side of the cage was difficult or impossible. One monkey recovered this function 20 weeks after the operation "a finding accounted for in terms of amount of tissue removed or differential training."

(7) Poor performance on the conditional reaction problem. In this type of problem which of two stimuli is the positive is conditional upon some other aspect of the stimulus situation. Black and white patches of various geometric patterns were used. When the black and white patches were small the animal responded to black to get food; when large to the white. Normal animals learned the problem. The frontal animals failed to learn it in a thousand trials.

(8) Poor performance in delayed reaction problems. Jacobsen found normal monkeys could delay 2 minutes. Lobotomy abolished the response and the animals could not relearn it. Size, shape and brightness discriminations were retained with no apparent loss, indicating that these are lower order functions.

Psychological Optics
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SPACE, TIME AND MOTION: XVIII

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In the preceding March paper of this series it was shown from several different types of experiments that sensory isolation and deprivation during early critical developmental stages produces an arrest of development. This arrest of development results in serious degrees of impaired functional proficiency even after attempts to repair the damage by systematic training. Goodman's rabbits and the chimpanzees of Riesen and Clark were essentially 'blind' for prolonged periods after dehooding; motor performances were characteristically different from those of the controls reared under normal lighting conditions. Whether the experimental animals may ever attain the same levels of functional proficiency which they would have reached had they not been reared in total darkness for about a year and a half remains to be seen. There are many reasons for believing that the organismic damage will never be completely eradicated. It would be fortunate if a perfect restoration could be secured.

The implications of these experiments for the early detection and proper handling of the visual development of young children is not only obvious, but the convincing proofs from Harmon's extensive Texas studies leaves no room for doubt.

The fitting of an appropriate lens at best can only transform the pattern of light energy distribution at the point of entry to the neuromuscular system, that is at the retinas.

The all important restructuring of the visual field and its integration with the adjustory movement sequences which follow and which constitute behavior has simply got to be done by means of a proper diagnosis of what have come to be termed 'skills' and thereupon an individualized program of realignment through training must be instituted. Nothing short of this approaches the ideal which I as a father have a right to expect when I take one of my children in need of professional visual services to the optometrist or the ophthalmologist.

In our last paper too it was pointed out that without the functions of the frontal lobes of the brain vision is in a sorry state. And the striking truth must be emphasized from the many studies of the frontal cortical functions (Fulton, Klüver, Lashley, Jacobsen, McCulloch, Ward, Finan, Walker, Warden, Harlow, and others) observed in animals after lobotomies that there is strong resemblance between the alterations of behavior here and with those observed in the deprivation experiments.

On page 19 of this volume (Vol. 9, No. 5) was reproduced a condensed summary of the eight functions notably impaired following the insult or destruction of the normal functions of the frontal lobes as given by Stanley and Jaynes (Psychol. Rev., 1949, 56, 18-32). These were general hypermotility or hypomotility, uncontrolled food intake, marked distortions of emotional and social behavior, lowering or ablation of ability in habit-alternation, weakening or abolishing of the perception of relations in tool using in the multiple-stick and platform experiments, and finally delayed reactions were abolished and could not be relearned.

On this last statement the issue seems to be unsettled. Harlow, Wade, and Malmo have found from their experiments that although the delayed response may be incapable of elicitation at once after lobotomy Harlow tested two monkeys after 36 months and got delays up to twenty seconds. Wade got better delays after giving his animals nembutal; and Malmo found that they did better if a visual signal was given for the correct response when the tests were made under low room illumination; Spaet and Harlow also got better results from an increased number of daily stimulations. All this may mean that the important delay function while clearly and unambiguously impaired may later be partially or totally restored.

Stanley and Jaynes, it seems to me, have presented an important new line of thought as to the functions of the frontal cortex. They propose that the eight kinds of functional losses which they described above "represent a single deficit." They assume that all eight spring from a single source. This is the postulated "cortical act-inhibition". I shall try to present as clearly and simply as I can the proposed theory with the recommendation that those few readers of these papers who have access to the Psychological Review read the original paper by these authors in the January, 1949, number.

The meaning of act-inhibition is made clear by first distinguishing between the discrimination and the delayed reaction experiments.

In a simple discrimination situation the animal is required to respond positively to a triangle, say, above one of two boxes containing food and negatively to a square above the other. "Animals with or without the frontal cortex can learn this problem with ease." How does the delayed reaction problem differ from this? Why is it so markedly impaired after the loss of frontal cortex function?

In the delayed reaction problem the animal "has learned to approach both stimuli." He has built up two positive approach habits of about equal strengths. In order to get food he must respond to one and not the other of two stimuli, which is contingent upon some previous event, let us say the sound of a buzzer at some fixed time before he is permitted to select one or the other of the food boxes. (An animal psychologist has been defined by some punster as a fellow who pulls habits out of a rat!) The essential thing in the delayed reaction experiment is that the animal must inhibit one habit mechanism which would take him to the wrong box. This is the thing which the frontal animals cannot do at all well in comparison with the normals. This inhibition of a well established but at the moment inappropriate habit mechanism is called act-inhibition "because it is not the inhibition of isolated muscle reactions but rather the inhibition of an entire response sequence."

The authors of the theory hold that the mechanism of act-inhibition must be cortical and that the neural function which brings it about is suppression.

The buzzer sounds. Twenty seconds later he looks at the triangle and the square. If the single stroke bell had sounded the right response would have been to the right hand box. But it was the buzzer; this means the right choice is the triangle which is over the left box. Positions are not important because the experimental design has taken care of that. As the animal looks at the boxes the immediate recognition of the two forms must be followed in the delayed reaction experiment by the suppression or inhibition, our authors say, of the inexpedient one of the two equally well organized habits. And he must be able to shift from one to the other in terms of the prior bell or buzzer, disjoined in time with this instigation of the problem solving movement sequence. How is this done?

Stanley and Jaynes propose the following answer: "The neural substrate of cortical act-inhibition is a spatio-temporal pattern of suppressor impulses which act on discrete foci of the cortex, rendering such foci temporarily inexcitable."

This is done neurologically by "the raising of the synaptic threshold of those neural units necessary for the execution of an observable response-pattern." How long the animal can delay is measured by how long inhibitory impulse patterns take to disappear from the suppressor areas. After a fairly long time (a few minutes) "the incorrect response is not inhibited." Either habit is now about equally likely to appear.

The authors give three possible answers to the question as to how destruction of the frontal lobes may account for the lack of act-inhibition as revealed by the failure of the animals in the delayed reaction experiments.

Let us insert in this discourse the notation emphasized in previous papers in this series that our human culture has evolved largely because we can make delayed reactions of comparatively long durations; much longer in fact than any other known animal. Our distance receptors plus the cortical and homeodetic circuits which maintain the stimulus give us an expansion and diversification of behavior impossible to any other primate. Let us also emphasize the tremendous effectiveness of vision in this scheme of things. Your reading and understanding of these pages, for example, is but an instance of the fact that LEAD means either what you do with the leash on your dog or a material used in soldering. Which one is appropriate al-

ways comes from the schemata or frames of reference active temporally just before your eye met the word.

The first answer as to the mechanism of act-inhibition is that there has been a destruction of the rostral portion of the prefrontal cortex which contains the most powerful suppressor regions known. The second is a disruption of an 'organizational' region for the previous region (designated LA in the cytoarchitectural system for primates of Bonin and Bailey.) The third assumes a disruption of cortical suppressor mechanisms involving all the suppressor strips "wherein mass action and possibly equipotentiality obtain." The authors think proposals two or two and three are adequate to account for the neural substrate of act-inhibition, but point out that the answer to the problem lies in future research.

The authors then pass to an examination of the 8 forms of impairment previously cited, applying their conception of the mechanism of act-inhibition to account for each type of impairment. One sample will suffice our purpose here. In 'explaining' the failure of the frontal animals with the multiple-stick-platform problem, we quote: "The stimulus stick arouses the response of grasping the stick and raking in food. To do the problem correctly, the animal must use first the stick to rake in another stick on another platform, then use the second to rake in the third .... (finally getting the longest stick which is the only one capable of reaching to food.) To perform such a series of acts the response of raking in food with the first inadequate stick must be inhibited, so that the animal will use it to rake in the second stick, on another platform. The frontal animal cannot inhibit this response of raking in food and consequently it continues to attempt to reach food with the first stick, which is too short, just as Klüver's monkey with the grapes, or the monkey pulling the latch."

Much as I admire the worth of the Stanley and Jaynes paper I must confess that the explanatory logic of the causation mechanisms of act-inhibition in these cases leaves me cold. The frontal monkey cannot inhibit the wrong movement because he cannot inhibit the wrong movement! To me the concept of act-inhibition is one of the first order advances in our thinking. But the proposed mechanism for it seems to me just as futile as are almost all the other attempts made by the neurologist and physiologist to explain the complex course of a perceptual or a manipulatory sequence in terms of stimulus patterns at the sense organs and then invoke some peculiar deus ex machina who conveniently raises and lowers synaptic thresholds in some incomprehensible way to produce the magnitude, the vector, in fact every property of the behavior act.

Why not grant at once what is so perfectly well established; no monkey or other animal can form spaced, timed and positioned manipulatory skilled acts unless he possesses some visual space perception and unless that has been integrated with his movement mechanisms from infancy on? What have the experiments cited in the first part of this paper conclusively shown?

Moreover, such explanations as this one of Stanley and Jaynes almost completely disregards the agency of the motor mechanism as something almost completely passive and always at the mercy of either the stimulus pattern or some switching device in the brain which decides what muscles shall contract, and in what order. It is my contention that a much better formula to account for act-inhibition can be written. All that is needed is the fundamental fact of the development and behavior of half-centers as was originally presented by Holt (Animal Drive and the Learning Process) together with the same mechanisms set forth in my previous papers on motor theory. This, it will be noted is the same mechanism of the servo type which is proposed by Winener in his Cybernetics. It is the thing proposed by Dewey as early as 1896 which led to the abandonment of the reflex as the unit of behavior. It is the thing which flexible, intelligent problem solution demands, that the motor consequences of any act may serve as a strong determinative of the course and consummation of that act. Why must we seek to account for the behavior of even higher animals in terms that imply that they are completely stupid? That they are incapable of seeing relations between sensory signals and the more and less expedient reaction possibilities?

Organic behavior which must be integral and efficient in order to live must be more flexible and transformable than rigidly oversimplified neural diagrams permit. Stanley and Jaynes close their paper with the observation that we must not think that act-inhibition is the only function of the

frontal lobes. Most assuredly! We know even now from the earlier experiments cited that fruitful organization of the transforming agency of prior experience is significantly deficient in the sense deprivatives. Halsted's emphasis upon visual signal handling in relation to the functions of the frontal lobes in intelligent behavior was not misplaced or overemphasized. In the behavior of animals with highly developed brain cortices it looks increasingly like the concept of field organization and field dynamics is a much more promising basis for thinking and research than the mechanistic simplicity of the stimulus-response doctrine.

Psychological Optics
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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: XIX

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In the previous two papers we have examined some of the evidence with regard to the functions of various parts of the brain. Our interest has been occasioned by the role played by the central distributing mechanisms in the visual functions which enable us to perceive the relations of space, time and motion. In the history of the scientific study of vision there was a long period in which almost the only attempts to handle the problems of resolution, form, spatial position, movement, etc., as well as the discriminations of color and brightness were limited to the eye and particularly to the retina. The discovery of the synapse soon became looked upon as a magic device to explain almost anything and everything. These switching devices enabled 'something' to couple the neuron conductors into canalized chains. Learning was thus a process of bahnung or trail blazing, laying down the tracks, in the wilderness of the brain and cord. It has taken about fifty years of patient research and recasting of theory to reach a position like Cannon's doctrine of homeostasis; like the concept of the organic circuit; to realize the full significance of the backstroke, or to reach the position so clearly stated by J. F. Fulton that the units of organization and of function in the central nervous system are movement patterns. They are not neurons or synapses nor chains of these. As has been pointed out, if a well educated man knows and can recognize a quarter of a million English words he would have to have this number of highly individuated circuits for words alone within the limited area of the form field of the central portions of the retinas. And so for all other types of discriminations. This kind of doctrine throws the fat right into the fire because at once if we elect to go along with such an out and out sheer mechanical theory we are faced at once with the problem of how we are going to handle such problems as symbolism, abstraction and generalization or others of the higher order mental operations.

Then, too, such conceptions of the fundamental neurological mechanisms of the body make it impossible for us to align the findings of research in our field of the study of functions with respect to such processes as we may observe in the visual perception, retention and later recall of patterns of impression. From the first there is a sequential series of transformations in the residual traces left in the conductor-effector system. No one ever recalls precisely what he has seen. The pattern is always transformed by the sets, attitudes, etc., which have been set up in prior experience. Goals have a definite way of transforming the means to these ends. Otherwise problem solution, invention, and the very basis of our cultural system would collapse.

In order therefore to reformulate the best possible working hypotheses for a theory of space, form and motion from the psychological or experiential point of view we must familiarize ourselves with the best information we have on the role played by the central distributing mechanism in these processes.

It is not surprising that a large number of the anatomists and neurologists are still looking at these problems in the effort to find solution to them in the architecture of the brain. Recently I heard one assert that all visual perceptions were functions of cytoarchitectural fields 17, 18 and 19. These comprise the classical visual cortex in the occiput. In our two preceding papers we have shown why such a position cannot be held in the present day.

In this paper let us add further facts. Here I wish to present in brief summary some of the conclusions of one of the world's leading investigators of the problems of the functions of the brain in seeing. For about thirty years important papers reporting his researches have appeared. I refer to Professor Karl S. Lashley of Harvard, formerly of Chicago University. I shall present in brief a few of Lashley's conclusions from a monograph printed in 1948 "The Mechanism of Vision: XVII. Effects of Destroying the 'Visual Associative Areas' of the Monkey" (Genetic Psychol. Mon., 1948, 37, 107-166.) and from his Brain Mechanisms and Intelligence, published in 1929.

In this latter work we find the following conclusions from years of careful studies probably matched by no other single scholar: In rats, dogs and monkeys the capacity to learn maze habits is reduced by the destruction of cerebral tissue; the reduction is roughly proportional to the amount of destruction; the same amount of retardation in learning is produced by equal amounts of destruction in any of the cytoarchitectural fields, hence the capacity to learn the maze (that is to form intricate habits of the spacing and timing of serial movements) is dependent upon the amount of functional cortical tissue and not upon its anatomical specialization.

The interruption of association or projection paths produces little disturbance of behavior so long as cortical areas supplied by them remain in some functional connection with the rest of the nervous system. In his experimental animals also Lashley showed that the "capacity to form simple habits of sensory discrimination is not significantly reduced by cerebral lesions, even when the entire sensory field is destroyed." He adds that the "immunity is probably due to the relative simplicity of such habits" and adds that in spite of the higher specialization in man that "the problems of cerebral function are not greatly different from those raised by experiments with rats."

With regard to the problem of the alleged neural pathways Lashley concluded that "learning and the retention of habits are not dependent upon any finely localized changes within the cerebral cortex" and that his results are "incompatible with theories of learning by changes in synaptic structure, or with any theories which assume that particular neural integrations are dependent upon definite anatomical paths specialized for them."

"Integration", he says, "cannot be expressed in terms of connections between specific neurons." The contributions of the parts of the brain are qualitatively the same. "There is not a summation of diverse functions, but a non-specialized dynamic function of the tissue as a whole." "The mechanisms of integration are to be sought in the dynamic relations among the parts of the nervous system rather than in details of structural differentiation."

It is hardly necessary to point out the incompatibility of these conclusions regarding the equipotentiality of the cortex and the mass action of the cortex with the classical theories. These studies, completed and printed twenty years ago, naturally inspired numbers of other investigators to test and repeat the experiments.

Let us now look at the 1948 publication by the same author. These studies are directed at the brain correlates of the symptoms of common visual disorders. Included among them are such things as depth perception, visual agnosia and alexia, form blindness, loss of color vision, etc. The experiments reported were an attempt to show the extent the production of the major symptoms of visual agnosia by destruction of the parts of the cortex which are assumed to perform the visual associative functions. These regions lie in the vicinity of the corpus striatum and correspond to Brodmann's areas 18 and 19 and also the frontal eye-fields which have intimate connections with the prestriate area.

The list of the visual symptoms studied includes fixation; difficulty in following moving objects or pursuit; dyslexia or lowered reading skills and Lange's 'optic number disorders'; depth perception; narrowing of the visual field of a nonscotomatous nature; optovestibular functions; distortions of the vertical; macropsia and micropsia; loss of color vision with retention of detail vision; failure to recognize objects in spite of adequate visual acuity; inability to describe the appearance of objects from memory; difficulty in understanding relations among objects, in interpreting pictures or following detached sequences of movement; aphasic disorders of language with special reference to visual objects; difficulties of space orientation and organization with particular relation to object recognition.

The locus of these types of disorders has been a matter of little agreement among the experts. For example Monakow wrote, from the clinical evidence in 1914, "I do not know of a single case in which a purely traumatic lesion in the occipital lobes of an otherwise sound brain resulted in a persistent visual agnosia." The situation today seems to be summarized in Lashley's statement that "the clinical evidence is inconclusive."

Next month we shall review the evidence from the experimental studies and complete with the findings set forth in Lashley's monograph.

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SPACE, TIME AND MOTION: XX & XXI

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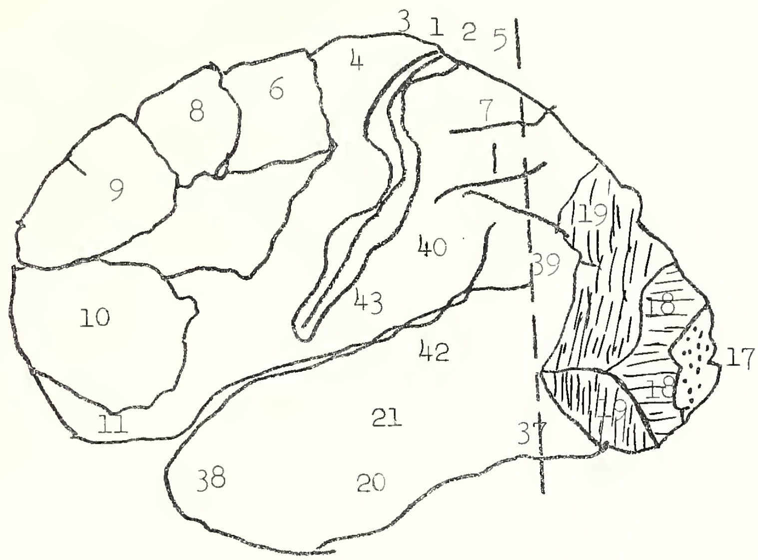
Flourens in 1823 discovered the fact that visual function is dependent upon the integrity of the brain cortex. The first known attempt to localize visual functions in the occipital lobe was that of Panizza in 1855.

Hitzig in 1874 however was probably the first to locate the visual cortex as the area striata. This is area 17 in Brodmann's map, first published in 1909, a partial sketch of which is reproduced below.



Brodmann's Map of the Visual
'Association' Areas

17 - Striate Area
18 - Occipital
19 - Preoccipital

From the retinas there is a fairly well established point to point relationship of projection to the lateral geniculate bodies. Destruction of primary retinal neurons causes the cell bodies of secondary neurons in the geniculates to degenerate - a fact known as transneuronal degeneration.

From the geniculates the optic radiations pass to the calcarine cortex. This is the region designated on the map of Brodmann as areas 17, 18 and 19.

The posterior portions of the occiput are asserted to be the locus of macular vision while the anterior portions of the calcarine contain the representation of peripheral vision. This means that the comparatively small area of the macula is extended greatly and the large extent of the periphery is likewise greatly restricted architecturally. Regions 18 and 19 are regarded as the visual 'association' areas. In fish and amphibians the forebrain may be removed with no impairment of vision. Rats and rabbits have a visual cortical area essential for pattern vision but light discrimination remains after total destruction of the occipital lobes. Light but not object vision remains with dogs, cats and monkeys after ablation of the occiput. Human beings are claimed to lose both pattern or object vision and light discrimination when areas 17, 18 and 19 are removed. (Marquis).

Areas 18 and 19 are said to be concerned with the functions of "visual association" and their injury causes disturbances in spa-

tial orientation of the visual image of the homonymous half-field; also visual word blindness (alexia). (Fulton).

Impulses from area 17 pass to 18, which is called the parastriate lobule, and from there they pass to area 19, the preoccipital area. Area 19 receives impulses from all parts of the cortex and consequently is regarded at the center for correlating and coordinating the visual "with other reflexes."

Surprisingly enough it is only with the last quarter century that the evidence supporting the above generalizations has been produced. In some instances it has been derived from observations on but a few animals. In other instances upon clinical observations where the exact delineation of the amount and range of tissue destruction was not wholly convincing due to the difficulties of neurological and histological techniques. At any rate scholars of the first rank like Professor Lashley found it difficult to subscribe to the rigid localization of visual functions which the above brief summary would tend to indicate. If we follow Sherrington's notion of the integrative nature of the central nervous system, and if we think of the role played by the chemical conduction systems, such for example, as that involved in the constriction and dilation of the pupil in response to variations in light intensity, and if we think of the fact that in such an elaborate dynamic system the redistribution of the field following the impairment of any single local area can hardly carry with it clean cut evidence of unquestioned causation and ascription of specific function to that area - these and other similar considerations simply raise the question of the mechanism of the functions of the calcarine.

It has been repeatedly emphasized that vision as a psychological set of facts can hardly be reconciled with the notion that vision can even exist in isolation from the motor system; the regenerative feed back inputs from the effectors has to be intact and functioning and the whole sensory-motor unification must not be disturbed or there will be loss or impairment of functions.

Moreover, the theory that the calcarine alone is the seat of all visual experiences runs head on into the fact that vision would be of extremely small usefulness to us without the supplement received from the functions of the frontal lobes.

As the late Professor F. L. Landacre once remarked to me the brain is still largely a dark continent. We really know very little of its mechanics as the substrate for the manifold of experiences such as our intricate discriminations of space, time and motion. It is therefore quite surprising to hear anatomists talk about 'visual images' in area 17! How can anyone conceive of anything in area 17 other than relatively slow moving volleys of weak energy; waves of electrochemical energy spread out literally all over the place as the projection of the macula and with the whole periphery limited to a very small central region farther forward?

Another objection to such a formulation as that indicated above is that it represents an out and out atomism. Complex perceptions arise out of the combination or summation of simple 'reflexes'. But how? Every attempt to keep such a theory alive has met with failure. Of one thing we can be absolutely certain: Nowhere has the doctrine of 'association' failed more completely than in the attempt to apply it to the explanation of perception. There has to be some mechanism of unification, structuring in field dynamics, organization, for the operational concept of the synergic organizations of figure and ground. Vision alone, said Berkely, cannot give us more than the first order raw material. There must be some agent of organization, some design or plan. Wholes come first, not parts, and wholes determine parts. The forces of organization "come from above", that is the pace setters are the dominating, causal, "heads" which produce individuation of movements and of perceptions out of the primary mass actions which are at first undifferentiated. Habits are not formed by the mere setting together of independent muscle twitches bonded together by 'association.' This point of view carries with it a great weight of supporting scientific evidence. It runs counter to the oversimplicity of certain current concepts of neurophysiology..

Lashley asked What are the effects upon visual functions if we destroy the visual "associative areas" of the monkey? Five monkeys were trained to perform a variety of visual discrimination processes. They were then operated sectioning off areas 17, 18 and 19, the visual 'association' areas. Careful tests of a wide variety of visual functions were then made over prolonged periods. The animals were then destroyed and the brains

sectioned and examined histologically in order to determine the exact extent of the lesions produced.

Damage was done to the radiations with almost no damage to the striate areas which thus were simply isolated functionally from the remainder of the brain. "The evidence was not conclusive but suggests that the defects (visual) were amblyopic rather than completely blind scotomata. If this is correct, amblyopia in man may be interpreted as indicating damage to the radiation rather than to the striate cortex."

In three of the five animals the greater part of the frontal eye fields were destroyed. In all five area 8 was completely removed. Two of the animals "showed no visual symptoms whatever" and a third had "some restriction of the left temporal field but discriminated food from other objects within a few hours after the operation."

There were no defects of eye movements. Tests of acuity (grasping a white thread to get small bits of food) showed almost no impairment in three of the five animals. In the other two they could see and act upon larger cords (2 mm. diameter). Moving objects, pieces of apple moved in front of the animal, were captured successfully. Tests of perception of distance and past pointing, while difficult, were made by placing bits of food at different distances and observing the movements to secure it. No. 1 "18 hours after the operation tended to reach beyond it but within two days reached quite accurately." Two others "reached and grasped food accurately as soon as they could reach at all." Every animal showed accurate appreciation of her extent of reach (40 cm) with an error of 2 to 4 cm.

With tests with colored plates "all the animals showed practically perfect retention of reactions to color and no confusion with changes in shade." Color vision, says Lashley, so far as measured by these tests was not significantly affected by any of the operations.

The recognition of common objects is lost in Lissauer's type of visual agnosia in humans. The monkeys were tested for this type of visual defect following the operations destroying the visual 'association' paths and hence the functional contributions of cytoarchitectural fields 17, 18 and 19. The tests were given as soon as the animals recovered from the immediate effects of the operations; within two weeks in all cases and before they had a chance to relearn the significance of the objects. The test consisted of discriminating food from non-food; recognition of the carrying cages; recognizing other monkeys arrearing in a window; general behavioral evidences of spatial disorientation. "In these tests there is clear evidence of the recognition of familiar objects by all animals after all operations" ..... "None of the operations produced any symptoms of object agnosia."

Lashley quotes Klüver and Bucy as stressing the tendency of their animals after temporal lobotomies to examine and re-examine every object with which they come in contact. Lashley points out that "No such behavior appeared in the monkeys with prestriate lesions." "On the few occasions when non-edible objects were picked up they were immediately discarded and the same object was rarely, if ever, re-examined."

No significant changes were noted in the tests of searching in the visual field, that is picking out food particles from inedible pieces of wood, a brass lock, harness ring, etc.

The slowing down observed by Poppelreuter in human subjects in searching tests was not observed by Lashley in his subjects.

As to the retention postoperatively of formal visual habits three experiments led to the conclusion that "differential reactions to colors and to simple visual figures survive the removal of a large part of the prestriate regions."

Tests of visual generalization were also made. These include such more complex functions as transposition, the conditional reaction and delayed reactions. The nature of these tests has been described in the three previous papers of this series and need not be repeated here. In a transposition experiment the animal reacts to a relation rather than to absolute dimensions, brightnesses, etc. "The results show clearly that destruction of the 'association areas' did not abolish the capacity for brightness transposition."

The conditional reaction is the most difficult visual generalization it has been possible to teach normal spider monkeys. The animal must select one of two objects ac-

cording to the character of the background on which they are displayed. Animals 1 and 5 "showed no bad effects of occipital operation on performance of this task." The remaining three animals were definitely deteriorated.

In the delayed reaction tests "all the animals succeeded in delays of 15 seconds or longer" except one which was intractable in all training problems.

Bilateral removal of Brodmann's area 8 did not cause hyperactivity in Lashley's animals. Individual traits of temperament were found to be exaggerated rather than reduced following the operations. "Two of my monkeys ... with bilateral lesions including the locus of area 8 (eye fields) and additional parts of the frontal eye fields showed no postoperative visual symptoms whatever."

None of the lesions in the prestriate region "has produced symptoms resembling object agnosia as described for man."

"My animals have shown no reduction of their capacity to distinguish and identify different shades and hues of colors, to estimate distance within about 5 per cent, to follow moving objects, to recognize familiar objects in the environment, or to retain formal visual habits."

"None was in any way disoriented in the monkey house or experimental rooms." "These capacities, disturbance of which makes up a large part of the syndrome of visual agnosia are clearly not dependent upon to considerable portion of the prestriate regions involved in these experiments."

Considering the more general case of the validity of evidence relating to the effects of cortical lesions on behavior Lashly points out that following destruction of Broca's area "there are almost as many negative cases on record ... as there are positive cases of aphasia."

In his own work with rats Lashley says "there is consistency only in averages; the individual cases may vary widely from the mean of a group with seemingly identical lesions."

At present available evidence indicates that "in the monkey all transcortical connections between the striate areas and other parts of the cortex are relayed in the prestriate region; that the striate areas have no long transcortical connections." "Integration of visual excitations with other cortical activities is apparently not dependent upon direct, restricted transcortical associative connections. The alternatives of multiple paths, of diffuse conduction through the cortex, and of relay through the thalamus remain open."

Lashley's findings do not accord with the results from clinical data as illustrated by a quotation from Ingham who says "it is assumed that the engrams of visual memory are formed in the areas 18, 19 and 39. It appears that area 18 functions in the recognition of form, color, movement, location, etc., and recognition of things seen; area 19 represents more complex combinations, integrations and relations, orientations and calculations, and is important in revisualization; and area 39 is specialized for the visual component of language." To this Lashley replies "the removal of all of the dorsal and lateral portions of these regions including the portions to loss of which object agnosia has been ascribed, has not resulted in loss or measurable disturbance of any of the functions ascribed to the region." Finally, there is "no present justification for ascribing object agnosia, defects of visual memory, or disturbances of perception to uncomplicated loss of tissue within this region."

So there! The evidence is before the jury. It would seem that one and only one inescapable conclusion must be drawn. The visual cortex of areas 17, 18 and 19 is not the locus of the principle psychological functions of the seeing of objects, space relations and forms. We must look elsewhere for a suitable explanation. There is no good reason longer to believe that the alleged "association areas" perform the function of what James called "seeing things together" or fulfill the attribute of appurtenance.

Psychological Optics
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SPACE, TIME AND MOTION: XXII

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In this paper let us take a summary look at the evidence presented in the last four papers regarding the problems of the localization, and mechanisms, of the principal visual functions in the brain.

What are the determinants of the qualitative and quantitative properties of the things we see? First, there is the theory that physical objects in physical and temporal space relations have in them specific organized or structured attributes. One object is bigger because it is more space filling. A group of different kinds of flowering plants constitute because of proximity, similarity, common fate, and such considerations, a flower bed and this in turn changes the whole nature of the garden and responses of the people who live with it, tend it and enjoy it. The lavender phlox partly superposes the yellow calendula and this contributes to the visual perception of depth and distance. The flowers look very differently in fog, in twilight, in bright moonlight and at noonday. If one closes one eye there is not only a restriction of the total visual field but the scene looks smaller, more distant and loses some but by no means all of its depth. Do the sheer physical properties of things determine how and what we see?

Only in part. If an affirmative answer is given to the above question we are committing the stimulus-error, that is ascribing to the stimulus-object attributes which are only derived from human discriminations.

And it must be clear that we must come to grips with the very fundamental problem of the precise nature of physical space. Is its proper descriptive measure or metric that in which the whole science of optics is written (with, of course, certain notable exceptions), namely the geometry of Euclid and the physics of Newton? Luneberg has brilliantly shown that it is not of this simple type. Space is curved. It "looks like" a single sheaf hyperbola. The shapes and sizes, etc., of things therefore become related to where and when they are positioned within this kind of framework. R. M. Evans has shown beautifully that when you photograph a red rose with a 'one-eyed' camera on a contrasting background and then on the flat surface of the ground you draw some lines representing the orthogonal projection from the eye position of some irregular rectangles the rose now looks precisely as if it were enclosed within a solid and real appearing transparent box! Similarly Hans Wallach has shown that if you place a series of black eccentric circles on a white disk and slowly rotate the figure within the visual field, motion adds the dimension of monocular depth. When viewed with one eye the circles jut out into space either in front of, or to the rear of, the supporting plane of the ground disk. No one who has witnessed these clever demonstrations can possibly doubt the fact, long known but too little considered, that depth and tridimensionality cannot possibly be an exclusive function of binocular vision. As we have pointed out in previous papers of this series the classical theory that depth and solidity in vision arises from the simultaneous excitation of corresponding points of the two retinas is not always true. It is not ever true unless this same element of space generating motion enters into the equation. This factor is provided by the fact of binocular alternation (retinal rivalry). As Washburn and others have shown when you abolish the pattern of the phi-effect, that is stop the alternation of monocular vision, depth disappears and the scene looks flat regardless of the fulfilling of the stipulations as to disparity and correspondence. The role played by the active touch and by the movements of the body in space in the genesis and development of form, position, size, and distance perception has been well known since the emphasis was placed upon these factors by J. M. Baldwin and others near the turn of the present century.

It seems clear that one need not deny the essential facts that the disposition in space of the objects comprising the visual

field is an important first factor in visual space perception. The objection is raised, and to many sustained, that to place the whole burden of determinancy upon this early first stage is wrong. To hold to the pure 'physical' theory of the reality of things is, as Eddington has put it, to refuse to face the fundamental problem; what, after all, are the reals of human experience? If you say that the physical stimulus constellation contains the releasing power of all the experienced qualities and intensities you then, ipso facto, deny the possibility for a science of psychology. You are then at once obliged to face the problem of explaining the utter lack of consistency and predictability which should follow, but certainly does not, from the postulation of such a point of view. It is for this reason that one often hears such position spoken of as one of the 'uncomfortable' postulates of science.

A second solution to the problem has been sought by the ascription to the sense organ of the determination of the attributes of visual experiences. Light reflected from patterns of objects is projected as two 'images' on many retinas. These are flat and two dimensional but decentered because of the interocular separation of the two lines of sight. Binocular vision is cyclopean, say these people. You see as if there were a single central eye. You must look, they hold, to the facts of geometric optics for the explanation of the visual attributes.

But we immediately get into troubles. If we grant that the lenses can and do form 'images' at the retinas then the essential function of these structures is to transform and convert the light patterns into slow moving volleys of pulsing, weak electro-chemical energy in the optic bundles. How can these <u>changed molecular</u> energy patterns carry the manifold meanings of the <u>molar</u> aggregates which induced them? There is no satisfactory answer. It is simply inconceivable how the <u>lightless</u> afferent volleys which now bear no spatial or temporal resemblance to the inducing stimulus can be seen-as the clear and well known objects of everyday recognition. Is there anyone who has watched the experiment of the serial reproduction of a visual form who is bold enough to deny that the repetition of the stimulus pattern extinguishes some portions and enhances other portions of the pattern until an approach to replication is attained? No. The function of the sense organ is to transform what it receives into something else. Look for example at the facts of size-constancy; at the lack of relation between the size of the retinal patch excited and the perceived size or distance. From simple facts such as these, well established, we must conclude that the answer of 'eye-ball' theory is not ample or adequate enough. Think of the weight of evidence from Sendens' observations on the aphakias; look at Riesen and Clark's experiments on chimpanzees reared in darkness for 18 months. Why did they not <u>see</u> perfectly immediately upon being taken into the light? Why did it take these animals so long to learn the simple visual recognition of the one source of subsistence - the nursing bottle? Why, one may well ask, have the experiments from my own laboratory shown that when an observer shifts from seeing objects at distance to near point he sees clearly within about a fifth of a second, but with two trained refractionists taking the static retinoscopic findings simultaneously, conjugate vision is not attained until from 5 to 35 seconds <u>after</u> the change in fixation. If the static retinoscope measures the lens power to give the null shadow, that is, conjugate vision or clear sharp retinal imagery, how is it that 50 observers tested all show this characteristic time lag yet they see clearly at once? To say that they 'have learned to interpret a blur' is to talk a language which I cannot understand. To me there is not a single defensible reason or a shred of evidence to support such a fantastic statement.

These and similar experiments have been made again and again during the past three years. They have been made by many leading optometrists. Observations have been made upon observers who had not the slightest knowledge of the nature of the experiments and with every possible precaution taken to exclude error. It looks more and more difficult to ascribe to the sense organ anything other than the function of serving as a detector of weak <u>signals</u>. It is certainly not a camera or copying device. It is assuredly not a power transmitting mechanism. There is continual wonder and admiration for the marvelous mechanism of the eye. But it is unwise and improfitable to ascribe to it gratuitously functions which it does not and can not perform.

Another way out of the dilemma is sought by those who insist that we look to the brain as the source of visual and other experiential qualities. In 1909 Brodmann mapped the cytoarchitectural regions of the cortex. The calcarine in the occiput was divided into regions 17, 18 and 19; 17 being the striate visual area presumably the locus of pattern or object vision and 18 and 19 the visual 'association' areas. When the afferent volleys reach area 17 and are relayed forward to 18, 19 and on frontalward, is it true that object vision is a function of the calcarine? Among other investigators of this problem perhaps none has studied it longer or more carefully than Professor K. S. Lashley. When cuts were made isolating these areas (17, 18 and 19) two of the five monkeys showed no visual symptoms of impairment whatever. After a few hours all could move the eyes properly, could see colors, discriminate food from nonfood, showed no consistent changes in acuity, were able to see motion, recognized all common and familiar objects, could make brightness transpositions, they could estimate distance within 5%; they were in no way disoriented in their living quarters. "The disturbances ... which make up a large part of the syndrome of visual agnosia are clearly not dependent upon the considerable portion of the prestriate regions involved in these experiments" says Lashley.

Speech is said to be controlled by Broca's region. Clinically Lashley points out that "there are almost as many negative cases on record ... as there are positive cases of aphasia" following injury or destruction of this region. One quotation from Lashley's work is particularly significant. He says "there is consistency (of results) only in averages: the individual cases may vary widely from the mean of the group with seemingly identical lesions.

There is, he says "no present justification for ascribing object agnosia, defects of visual memory, or disturbances of perception to uncomplicated loss of tissue within this region" (that is within the so-called visual regions of the calcarine).

Studies on the functions of the frontal lobes show that these regions play a distinctive role in visual functions. But again it must be noted that any theory which attempts to make the brain the generator of distinctive visual attributes meets at once the objection that without the effector system there is no evidence that any visual function of any significant usefulness to the organism is left.

Vision evolved, through millions and millions of years, to aid in the approximation and correction of manipulatory movements. So it is not strange that a fourth approach to the problem of the attributes should be sought in the tactual, kinesthetic and manipulatory movement systems and the feedback input mechanisms of the backstroke as the agent of integration and maintenance. This has been dealt with in this series of papers under the heading of motor theory. Our space, time and motion discriminations are certainly basic and fundamental to the organization of our culture patterns. Curious, is it not, that in separate tabulations of the most common nouns, both in the English and German languages, the one most common of all the common nouns is .... time. When is just as important as where.

To set up an acceptable theory of space, time and motion it is not necessary to deny or disregard the other components discussed previously in this and other papers of this series. It is only necessary to emphasize that seeing is not done with the eye or brain or effectors alone, but in a nicely balanced synergy of the whole integrated set of systems within systems. The common denominator of the whole process is movement.

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: XXIII

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In previous papers of this series we have noted the results of studies in which animals have been reared in visual isolation for prolonged periods and then admitted to lighted surrounds, with the consequent effects of the arrest of normal development of visual functions; we have examined the studies of Lashley, Klüver, Jacobson, Harlow and others in which portions of the occipital lobes have been surgically isolated. There remains to present a summary of the evidence from still another source. This has to do with the important studies of Bender and Teuber* on some 68 cases of brain injuries studied by them at the Navy hospital in San Diego.

These authors point out that prior to the first world war the problem of the nature and extent of visual disturbances following brain injuries was "rarely studied in detail." Except for the work of Head and Rivers in England and the monograph of Gelb and Goldstein in Germany there was little in the literature, and this, as Lashley and others have pointed out, often ambiguous and none too satisfactory. Frequently the number of case studies was small; all students of the problem recognized the dilemma that while injuries to the calcarine often yielded point to point predictable regional losses of visual function yet conversely there were also observed instances of "generalized alteration of functions in those parts of the field where vision is preserved."

Alterations of remaining functions could and did occur in the region of a relative scotoma or in areas adjacent to a relative or absolute scotoma, or as Bender and Teuber point out in the above paper, "they may also occur in areas which are far removed from any field defect demonstrable by standard perimetry." Lesions in any portion of the calcarine, they hold, may alter the function of the remaining visual cortex in a systematic fashion. "Such a fact is not readily reconciled with any concept of cortical function which relies on activity in a mosaic of neurones." This point I have emphasized repeatedly in previous papers of this series. The facts of closure or perceptual filling, of contrast, of visual apparent movement, are instances of perceptual functions which cannot be satisfactorily 'explained' in terms of the conventional theory of reinforcement, recruitment, summation and inhibition, etc.

To this reviewer of the work of Bender and Teuber it seems quite clear that these men have made a further important contribution to visual science from their studies on the measurable changes in the perceptual functions of 68 Naval casualties "with penetrating wounds of the occiput." Their studies included observations and measurements of (1) changes in various visual thresholds; (2) alterations in the formation of contours; (3) changes in the localization of objects in visual space; (4) disturbances in the perception of motion.

One of their main problems was the question whether these functions were altered separately or concomitantly. From their studies the evidence points to the fact that no function studied was deranged in isolation from concomitant alterations of other related functions.

I shall attempt to summarize in this paper some of the principal findings from the Bender and Teuber studies of the perceptual functions of these 68 brain injured men. These I shall take up in the same order as the authors presented their findings in the paper cited above.

The first topic they designated Fluctuations. There was a marked increase in fluctuation of all visual thresholds. Targets of any size, seen on any type of background, fluctuated irregularly and spontaneously in

* Bender, Morris B., and Teuber, Hans-Lukas, Disturbances in Visual Perception Following Cerebral Lesions, J. Psychol., 1949, 28, 223-233.

clearness or distinctness even though the physical stimulus remained unchanged Fluctuation was found to be maximal in a relatively amblyopic region or "may be the only obvious sign of damage in an otherwise normal-appearing visual field." Fluctuation was increased with decrease in illumination intensity and also by an increase in the complexity of the background upon which the targets were seen. This finding is confirmed by observations from our own laboratory with normal observers viewing visual forms.

Bender and Teuber also show that when the fixation duration is prolonged fluctuation increases and may end in complete extinction of or disappearance of the target. Blinking or momentary interruption of illumination brings it back, thus disproving the assumption of some that the extinction is due to "fatigue" effects. The authors hold that "these fluctuations are an important factor in the seemingly inconsistent results of acuity measurement of such patients."

The second kind of change the authors call Obscuration and Extinction. When, for example, a second test object was introduced into the field the first one became indistinct or obscured. This is a sort of converse effect to the well known Schumann effect in which looking for the appearance of a second target somewhere eccentric to the first may produce a diplopia or the perceived appearance of the second target. The authors state that "a target exposed in one part of the patient's field may become totally invisible for him as soon as another target is introduced into other, less affected regions." They also state that "with the method of double simultaneous stimulation we can thus demonstrate a relative deficiency of function in a homonymous half-field or quadrant which may appear intact on ordinary perimetry."

They report that extinction depends on relative intensities but not in a simple manner. "At times, a weak stimulus may extinguish a perceptual response elicited by one of considerably greater strength." Extinction depends upon time relations between stimuli; there must be time for the effect to 'build-up' or 'spread' before it affects the activity corresponding to the first stimulus.

"In ordinary vision (in contrast to perimetry) certain field defects may be due to a continual extinction in corresponding areas rather than to an actual loss of function caused by complete destruction of tissue." This fact may thus help us to account for the completion or filling of figures partly exposed in scotomatous areas.

In regions which according to perimetry were "blind", Bender and Teuber found that patients could see in these regions under certain conditions, the most important of which was the time of exposure. Completion was most likely to occur, they found, if the exposure times were of the order of 1/10 to 1/50 second in duration. "When exposures of the figures are sufficiently rapid, extinction does not have time to occur " This fact is likewise in accord with our own studies and thinking with regard to the beneficial use of tachistoscopic training for those whose visual form perception is weak and unstable, particularly in the case of weak readers.

A fourth topic studied was Alterations in Visually Perceived Shape. The authors noted that contour formation took more time in defective regions of the field than in those of their normal controls There was a lack of stability of contours; excessive gamma movement and recession in tachistoscopic exposures The most significant changes in pattern vision found were "various deformations in the contours of stationary objects." These distortion were seldom erratic and the authors noted that they appeared as simple rotations of the object in the frontal parallel plane (cylinder axis?) or an increase or decrease in the apparent size of the target. The change in size to smaller was the more frequent change. This finding accords perfectly with Ewalt's unpublished results secured upon "accident prone" street car and bus operators.

Fields may become more anisotropic following injury or disease. Movements in straight lines become curved; positions on the z axis may be increased or decreased in the forward-back dimension of space.

A major important finding of Bender and Teuber under this heading was that "Visual forms can no longer be transposed from one area to another without major alterations in their appearance," and that "the different regions of the field have lost their approximate functional equivalence." This fact seems to the reviewer to be of tremendous significance.

The fifth topic reported comprised observations on Alterations in Spatial Organization in Visual Perception. They noted that "patients behaved as if the coordinates of their visual space had been altered, so that anything exposed, say to their left, lower quadrant will appear curved, too large or too small, too near or too far." The distortions were consistent in direction in past-pointing when asked to locate or touch a target in an impaired region of the field. Errors made in attempting to bisect a line varied with the orientation of the line with respect to the normal Cartesian coordinates. Distortions involved all three dimensions of space. The most frequent manifestation noted was "an excessive apparent distance of objects in certain regions" causing the patient to overshoot the mark when he attempted to touch an object in that region. Along with this there was fading, loss of contour sharpness, desaturation of colors, in the impaired fields. Does not this evidence point clearly to the importance of size-constancy measurements from the diagnostic point of view?

When an object was brought into the regions of the impaired field the apparent speed of movement was observed to be enhanced.

The sixth set of observations was on Fusion and the Critical Flicker Frequency. Normally the c.f.f. is high in the center, slightly higher in a paracentral zone and then tapers off toward the periphery in all quadrants. In the defective field Bender and Teuber found a lowering of the c.f.f. "In all cases the perception of flicker and the perception of motion were concomitantly altered". Both the direction of the perceived path and the rate of movement were distorted. A single moving spot of light was seen as double or multiple images, often curved when in the affected area, and this effect was noted both in monocular and binocular vision.

The normal phi-effect could not be obtained in two patients who were studied and the authors conclude that disturbances of both 'real' and apparent movement are concomitant.

In discussing the significance of their findings they note that while there is no completely satisfactory theory at hand at present to account for both normal and disordered perception they suggest that a step in this direction may be made by considering the fact that flicker, apparent movement and real movement being simultaneously altered suggest some unitary physiological limiting mechanism for the three functions. Of course we may note that it is also a possibility that here we may be dealing not with three functions but with three aspects of a more general thing.

The striking similarity of their findings with those first discovered by Köhler in his studies on figural after effects and satiation is noted.

Confirming evidence on this point has been secured in our own laboratory in recent months. When a portion of the field is satiated, say in the upper right quadrant, there is a statistically reliable alteration of the critical frequency for fusion (flicker limen) in the lower left quadrant. The effect is proportional to the distance from the locus of satiation. This is the effect which Köhler has designated as the distance paradox. The effect is greater in three dimensions than in two dimensional vision.

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

SPACE, TIME AND MOTION: XXIV

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This paper will present a summary of the eleven papers of Vol. 9, together with some commentaries on the significance of the studies reported in this series.

Orientation in space and time is primary and fundamental. That is, the person must know where he is with respect to his surrounds and he must not be too inaccurate in his timing. If there is any amount of disorder in these functions, the perceptions of form, size, position, distance and motion are reduced in effectiveness. If the functional disturbance is severe enough the person may be sufficiently reduced in efficient performance of his professional, social, recreational and personal activities that he must be regarded as no longer self-sustaining. He must be helped by some other person, agency or institution to protect both him and society. It requires no elaborate brief to support the theorem that the perception of space, time and motion is a fundamental requisite to a productive and happy life in any station.

In Vol. 8 of this series I reviewed the tenets of the classical theories of visual space. In the main and with few exceptions they arose out of the attempt to apply the satisfying constancies of measurement and mathematical formulation which had been formed to work well in the 'physical' sciences. But could the same descriptive system operate with equal satisfaction in the realm of the living whole organism? Could it describe and explain the functions of space, form, size, distance, position, time, movement?

Depth and distance in geometric optics arise out of functions derived from accommodation and convergence. Parallax and perspective were set down as the geometrical conditions - the intervening variables - which carried the causation of the phenomenal space experiences.

It was not until 1838 that Wheatstone discovered the stereoscope and 14 years later the pseudoscope. It has taken us almost a century to discover "that the stereoscopic effect occurs only when other cues to space do not interfere" (Boring); that the two eyes can fuse and good depth be seen either when they converge or diverge; that single, clear vision of objects can be attained several seconds before vision is conjugate; that, granting all the established facts about accommodation and convergence, we must still recognize the powerful agency of field forces in the organizing and structuring of space and form experiences; and finally that "space is transposable" (Luneberg) in the mathematical and in the phenomenal sense and that this fact serves for us as the firm foundation upon which the concepts of learning and training as the mechanisms of transformation are grounded. Can a single visual function be named which is not susceptible to practice effect? Can any one be named which, except by merest accident, matures by and of itself, unaffected by the course of, and transforming agency of, experience? The weight of the evidence is for the negative.

George Berkeley in 1709 recognized the fact that sheer distance is only an abstraction and cannot be perceived immediately. Further he raised the question why, as later work demonstrated, an average observer can see objects tridimensionally at a distance of about 1320 feet, or 440 yards or about a quarter of a mile. But, in the classical optics, accommodation only operates to about two meters and convergence only to about six. Clearly the space of geometric optics was a space "world with man left out" (Titchener) and far from satisfactory if our fundamental interest is not optics but how we see.

Two bits of evidence were cited which bear upon the problem. Wilhelm Stern showed that in the languages of primitive peoples the words used to designate space and space relations originated out of the "personal dimensions" of right-left, above-below, before-behind the observer. These placed

the observer at the zero origin of the Cartesian co-ordinate system of the x, y and z axes. Among Indian tribes likewise he showed that the earliest space notions were egocentric, designated in terms of body mechanics and movements.

Minkowski, Peiper, Coghill and others studying the ontogenesis of functions observed that in the fetal stage the arm or leg responds promptly but not consistently to stimuli arising within the body as a result of specific posture, but does not respond to external or distance receptor stimulation. For the infant external, surrounding space and private, body-centered space are one and the same. It is not until the active touch and manipulation and distance receptor surrogation are learned that the "out there" moves away and becomes differentiated from personalistic frames of reference. Binet, Henri, Peterson and others showed that the 'local signs' of the skin were really orientation habits and the concepts of movements as early, primary, undifferentiated mass-acts and the subsequent individuation of movements reinforced the evidence from Stratton, Peterson and Ewert's experiments on retinal inversion and conversion and P. T. Young's acoustical transposition of the ears. Judd's studies and my own three papers on the localization of points stimulated on the skins of congenitally blind and seeing children and adults gave additional evidence against the nativistic theory. Whether one likes it or not space is a manipulatory projective set of skills which have to be learned like any other habit. The postulates of physics and physiology, do not take into account the age, cultural and occupational differences. Space is a stereotype for them, the metrics of which are the same for all ages, races and cultures. This is why vision is so largely and so inescapably a psychological problem. These were the arguments of the first two papers of Vol. 9.

Paper No. 3 presented the theory that in visual space perception the essential mechanism for the centering and synergizing of the eyes is the backstroke, or the regenerative feed-back input of the motor or effector apparatus. It probably serves as the integrator of the differing impulses which reach the central mechanism from all of the other sense organs and very likely serves as the basic mechanism, in conjunction with the frontal lobes, in determining what kind of adjustory movements follow upon retinal stimulation It was proposed that, all things considered, we could agree with Köhler, that "every perceptual theory must be a field theory", and that we may add also that every perceptual theory must be a motor theory. The perceptual act is thus to be regarded as the prophase or first term in the series of events which lead to the ultimate consummatory or adjustory movement of naming, speaking, locomotion or manipulation.

The fourth paper developed the notion of the problem of the attributes of sensory experiences and attempted to show that historically the unsatisfactoriness of the classes of attributes gave way to space as a functional perceptual unity. The movement to look somewhere other than to the sense organ for the answers to the space problems shifted to the brain. The substance of papers 5 to 11 comprised an attempt to review some of the most significant recent literature regarding the functions of various regions of the brain in the perceiving of space, form, motion, etc.

The frontal lobes function in a visual manner which indicates clearly that seeing beyond the mere stage of Bartlett's 'generic object' is not done in the occipital cyto-architectural regions 17, 18 and 19. The experiments of Goodman (1932) on rabbits reared in darkness and the chimpanzees of Riesen and Clark (1947) and the monograph of Senden (1932) on aphakias indicate clearly the fact that isolation and sensory deprivation results in an alteration of several highly important, visually instigated and controlled functions. Similarly injury or damage to the frontal lobes induces similar kinds of impairments. These were listed in a paper by Stanley and Jaynes (1948) which was reviewed, showing that in the higher anthropoids lobotomy induces radical changes in personality, tending toward the nonsocial, self-centered type of existence; weakness in planning, problem solving of any beyond the simplest types; break down of the delayed reaction; marked impairment of those functions which involve the concept of act-inhibition, a thing of the greatest importance and hardly explicable in terms of the conventional notions as to canalized nerve conduction paths. The reader is advised to reread pages 22 - 24 of paper 6 in which a proposal is made that the mechanism of act-inhibition can be found in Holt's concept of the development of and functioning of the half-centers in the 'education of sensory surfaces.'

Lashley's (1948) very important monograph on the effects of destroying the 'visual associative areas' of the monkey was next reviewed.

To what regions, particularly fields 17, 18 and 19, of the brain can visual functions be ascribed, such as: depth perception, visual agnosia and alexia, form blindness, loss of color vision, etc.?

The areas destroyed were Brodmann's areas 18 and 19. The clinical evidence as to the above functions in relation to 18 and 19 was, according to Lashley, Monakow and others, inconclusive. Five monkeys with areas 17, 18 and 19 isolated functionally from the rest of the brain were studied. Tests of acuity, motion, spatial localization, distance perception, color plate discrimination, recognition of common objects, recognition of surrounds and other monkeys showed no significant impairment after the operation. Visual habits formed before operation, such as differential reactions to colors and simple visual figures, "survived removal of a large part of the prestriate regions." The operation did not abolish the capacity for brightness transposition. In the conditional type of reaction, the most difficult visual generalization it has been possible to teach normal spider monkeys, two of the five animals showed "no bad effects of occipital operation" on the performance of the task while three "were definitely deteriorated."

No lesions in the prestriate area produced "symptoms resembling object agnosia as described for man." Lashley concludes that there is "no present justification for ascribing object agnosia, defects of visual memory, or disturbances of perception to uncomplicated loss of tissue within this region" (Areas 17, 18 and 19). There seems to be no justification for further ascribing to the "visual association" areas James' function of "Seeing things together" of subserving the attribute of appurtenance.

Finally in paper No. 11 the monograph of Bender and Teuber (1949) was reviewed. This work represented observations in a Navy Hospital of 68 men "with penetrating wounds of the occiput." They found marked variation and shifting of visual thresholds, field changes involving extinction and obscuring of parts of the field; marked changes in perceived shape, lack of contour stability; reduction in apparent size of objects; radical changes in the perception of apparent and 'real' movement; space coordinates altered; fusion and flicker frequency distorted. Apparently disturbance of any portion of the total field induces functional changes in other regions of the field.

It seems, in the light of the evidence, that we cannot ascribe specific visual functions to specific regions of the brain. Nor can we relate them to the sense organ. Hence it would seem that we must look to some species of a field-motor theory for help in the attempt to advance our knowledge of the space of our common experience. Subsequent papers will be directed toward such an objective.